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ARTS

POTENTIAL OF VIBE CODING DESIGN IN INCREASING DIVERSITY OF UI DESIGN STYLES

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Abstract

This article investigates the transformative potential of vibe coding — a text-to-interface paradigm — in diversifying user interface (UI) design styles and its broader implications for professional practice. By employing Large Language Models (LLMs) to generate executable code directly from natural language prompts, vibe coding lowers entry barriers for non-designers while automating labor-intensive production stages. Utilizing memetic theory and a systematic analysis of implementation cases, the study explores the tension between automated stylistic homogenization and the emergence of non-trivial, naïve, and artisanal design solutions.

The findings indicate a significant shift in professional roles: while automation risks deskilling junior designers by interrupting traditional learning routines, it elevates senior practitioners to roles focused on curatorial authorship and metadesign. The research concludes that the industry is heading toward a strategic bifurcation: a mass-market segment dominated by standardized, utilitarian machine-generated interfaces, and a premium craft design through human-led innovation. This evolution compels the professional design community to redefine its identity, shifting from functional problem-solving toward conceptual authenticity and complex visual manifesto.

Keywords: Vibe coding, UI design, Generative AI, Memetic evolution in design, Zero-interface, Designer deskilling, Design diversity, Craft user interface, Computer technologies in design.

Introduction

Vibe coding, which enables interfaces to be created directly from text commands (prompts), employs the zero-interface paradigm, opening the field of UI design to participation by non-designers while simultaneously automating previously labor-intensive stages of production. This innovation could potentially reshape aesthetics, professional skills, and cultural evolution in the field of UI design. Key opportunities to increase stylistic diversity include memetic evolution, alongside challenges like the erosion of professional standards and the commodification of design outcomes.

In practice, vibe coding remains a tool rather than a replacement. It lacks the critical discernment required for professional evaluation. Designers must still validate aesthetic coherence, ensure usability compliance, and verify the logical flow of the interface. Ultimately, a human expert is necessary to guarantee that the final product provides genuine utility for end users.

Problem Statement

This research examines whether vibe coding can counteract the homogenization of UI design. As AI integration begins, a conflict arises: does automated style recombination foster aesthetic diversity or accelerate the replication of existing patterns? The core challenge is determining if AI can drive visual innovation without compromising usability and professional standards. Consequently, this study investigates AI as a catalyst for design diversification during its professional adoption.

Methodology and Source Base

This study employs a systematic analysis incorporating memetic theory to examine the evolution and diffusion of visual styles as cultural units. The historical comparative method is utilized to contrast current automation trends with previous technological shifts in design. Through a thematic synthesis of implementation cases, the research evaluates the transformation of professional standards and the tension between automated standardization and creative diversity.

Recent years have seen a rapid expansion in research regarding UI generation via text commands and vibe coding, tracking with advancements in large language models (Li et al., 2025; Zhao & Tu, 2026; Horvat, 2025; Si et al., 2026). Research into regional diversity of AI practices notes the increasing sensitivity of large language models (LLMs) to cultural and geographical nuances (Wang et al., 2024). Specifically, various countries are developing sovereign LLMs trained exclusively on their own cultural data (Sengupta et al., 2023; Nguyen et al., 2025).

Recent studies highlight the value of text interfaces in enabling non-technical users to create digital solutions (Bañuls-Lapuerta et al., 2026), radically lowering the barrier to entry (Fawzy et al., 2025). Technology has reached a level where non-specialists develop functional digital products without knowledge of architecture or frameworks, expanding traditional approaches and enabling rapid experimentation (Hemdev, 2025).

From sociocultural and organizational perspectives, literature confirms a profound shift in the division of labor. While automation accelerates production, it risks devaluing practical skills among junior specialists, sparking debate over the future professional talent pool (Catalini, 2026). As automation absorbs measurable tasks, unquantifiable design aspects — intuition, human connection, and cultural context — become

scarce, yet the younger generation may lack the practice to develop them (Ciaschi, 2025). Furthermore, the design industry increasingly follows a management logic prioritizing speed, cost reduction, and measurability. Generative AI is viewed as a tool for radical optimization, potentially transforming creative activity into standardized production (Hernández-Ramírez & Ferreira, 2024). AI transforms professional competence in UX design and software development, highlighting a tension between productivity gains and the risk of eroding professional identity and foundational learning (Zulu et al., 2026). On the other hand, computer technologies such as Generative AI and VR are revolutionizing creative methods and automating production; this transformation necessitates an examination of the resulting socio-economic shifts and the legal challenges surrounding copyright and artistic authenticity (Bilozub et al., 2025). The issue of the balance between creativity and usability was raised by Salyha in a study dedicated to UX/UI education for students (Салига, 2025; Salyha, 2026).

The concept of memetic evolution in human culture was introduced into scientific discourse by Richard Dawkins in The Selfish Gene (Dawkins, 1976). Mullican's research expands on this by exploring the application of evolutionary algorithms in design, where traditional genes are replaced by visual memes — discrete units of cultural information. The author advocates for a shift from conventional modeling toward a generative process centered on three core operations: phenotypic blending, memetic meiosis, and meme splicing. In this framework, the computer facilitates variation and mutation, while the designer acts as the selective agent, utilizing subjective criteria to identify innovative forms. This methodology enables an efficient exploration of vast solution spaces by synthesizing objective engineering parameters with human aesthetic intuition (Mullican, 2005).

Research Findings

Vibe coding is a paradigmatic shift in UI development where layouts and interaction scenarios are created directly from user prompts without explicit manual design interventions. This technique relies on Large Language Models (LLMs) and multimodal AI to interpret natural language descriptions and convert them into executable interface code. This simplifies prototyping and iteration for both technical and non-technical users. Translating high-level user intentions into detailed UI design expands UI production beyond traditional tools, correlating with the philosophy of the zero interface (Салига & Павлюк, 2025). This marks a fundamental shift of control from manual configuration to systemic affordances that anticipate and react to human intent. A critical factor for both vibe coding and the zero interface is the formalization of prompt engineering. In this process, designers, programmers, or end-users formulate actionable intentions, constraints, or goals in natural language for AI interpretation. Synthetic affordances mediate between human intent and machine logic, bridging the semantic gap and improving development inclusivity.

The implementation of vibe coding in UI design reconfigures the hierarchy and structure of professional skills. While design education previously focused on iterative sketching and visual craft, core competencies are shifting toward prompt engineering, semantic mediation, and the critical evaluation of AI-generated solutions. This elevates the role of curatorial work, where designers orchestrate and finalize prompts to meet user needs and represent brand identity. AI is capable of adhering to accessibility standards and cognitive load requirements; however, this domain remains characterized by numerous subjective factors that necessitate human intervention (Салига & Ситник, 2025).

One of the primary deficiencies in contemporary UI practice is the propensity toward stylistic homogenization — the repetitive use of standardized systems, libraries, and frameworks that results in interface uniformity across disparate applications (Adams, 2013). Prompt-based generative tools demonstrate the potential to overcome this inertia by surfacing non-trivial and unconventional style combinations. AI can act as a catalyst for cultural and creative evolution by treating design elements as memetic units that replicate, mutate, and propagate through generative processes to augment human design process and predict trends (Pennefather, 2023). Generative systems respond to varied prompts, which encourages constant experimentation and overcomes creative stagnation. This shift suggests a future where digital design prioritizes stylistic diversity as a core value.

Analysis of corporate and independent projects reveals that autonomous initiatives produce greater inter-project diversity but also a higher degree of intra-project inconsistency. This underscores the necessity for a curatorial balance between innovation and quality of experience. AI transforms design from a labor-intensive human activity into automated learning loops, shifting the designer's role toward strategic sensemaking and the essential control of generative systems to prevent excessively eclectic outputs (Verganti et al., 2020).

The acceleration of memetic evolution through vibe coding radically alters the very mechanics of cultural inheritance in design. In the traditional model, memes — discrete interface elements such as the hamburger menu or buttons — were transmitted between designers through a process of conscious learning and replication. This was a slow trajectory, where each new variation passed through the filters of human logic and professional standards. Technology, in the form of generative AI, is capable of performing the horizontal transfer of traits across entirely different interface domains. It can instantaneously cross-breed the aesthetics of an 1980s game controller with the functionality of a banking application, creating a multitude of hybrid variants that would be physically impossible for a human to achieve due to limitations of time and attention.

Such technical acceleration transforms the design process into a particle accelerator for ideas. Whereas design systems previously evolved linearly and predictably, vibe coding introduces an element of random mutation into the system, which is critical for evolution. When a user unburdened by UX/UI conventions inputs a query, they unconsciously provoke the machine to

generate atypical combinations. This leads to an explosive growth in diversity, where technology assumes the role of a variance generator, and the human shifts from creator to a factor of natural selection. Only those memes survive which the designer or stakeholder recognizes as aesthetically compelling or useful, thereby forming a new cultural stratum.

Consequently, vibe coding paradoxically does not eliminate professionalism but rather propels it into the realm of high art and complex meanings. This creates an environment where standardized solutions become digital commodities, and true diversity is born at the intersection of uncontrolled machine recombination and acute human taste that rejects the banal in favor of the radically novel. At present, the capabilities of AI in generating complex, stylized interfaces remain limited, often yielding results of low aesthetic quality (see Fig. 1, Fig. 2). However, as the technology evolves, the quality of these outputs is expected to improve.

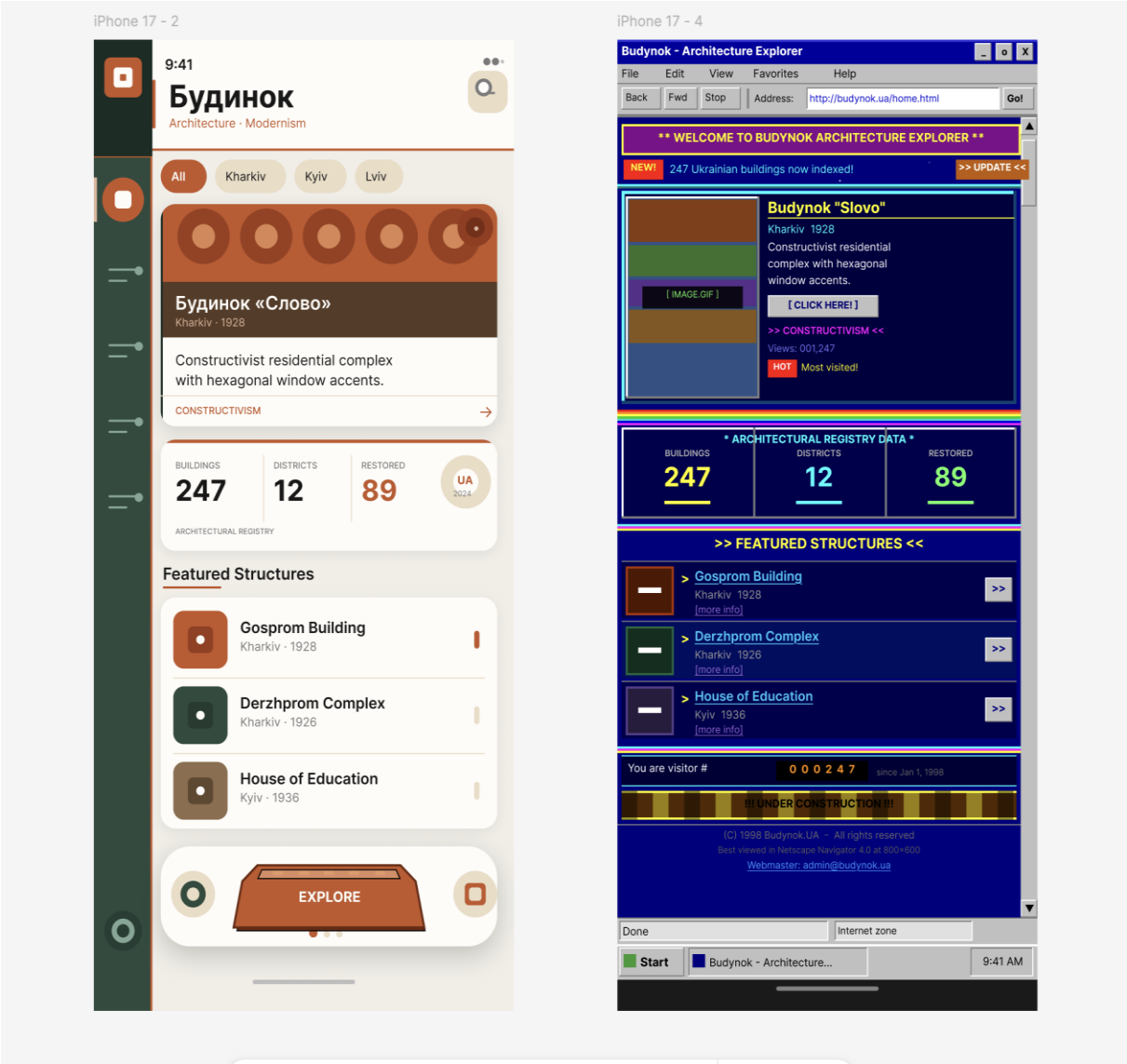

Fig 1. Example of mobile app UI stylizations based on text intent, generated by AI Claude Code v2.1.117 integrated into Figma Desktop App version 126.2.10. Screenshot taken on 09.05.2026.

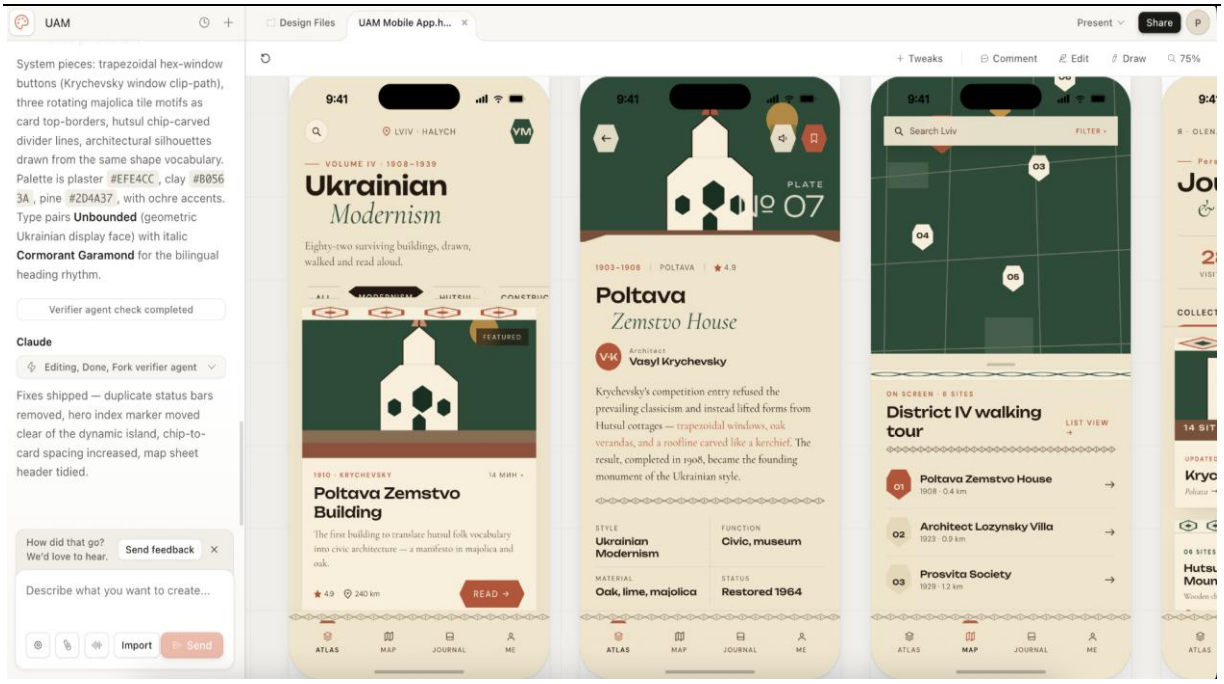
UAM
System pieces: trapezoidal hex-window buttons (Krychevsky window clip-path), three rotating majolica tile motifs as card top-borders, hutsul chip-carved divider lines, architectural silhouettes drawn from the same shape vocabulary. Palette is plaster #EFE4CC, clay #B0563A, pine #2D4A37, with ochre accents. Type pairs Unbounded (geometric Ukrainian display face) with italic Cormorant Garamond for the bilingual heading rhythm.
Verifier agent check completed
Claude
Editing, Done, Fork verifier agent
Fixes shipped — duplicate status bars removed, hero index marker moved clear of the dynamic island, chip-to-card spacing increased, map sheet header tidied.
How did that go? We'd love to hear.
Send feedback
Describe what you want to create...
Import
Send
Design Files
UAM Mobile App.h...
Present
Share
Tweaks
Comment
Edit
Draw
75%
Ukrainian Modernism
Eighty-two surviving buildings, drawn, walked and read aloud.
Poltava Zemstvo Building
READ
PLATE № 07
Poltava
Zemstvo House
Vasyl Krychevsky
Krychevsky's competition entry refused the prevailing classicism and instead lifted forms from Hutsul cottages — trapezoidal windows, oak verandas, and a roofline carved like a kerchief. The result, completed in 1908, became the founding monument of the Ukrainian style.
Ukrainian Modernism
Civic, museum
Oak, lime, majolica
Restored 1964
Search Lviv
District IV walking tour
Poltava Zemstvo House
Architect Lozynsky Villa
Prosvita Society
ATLAS
MAP
JOURNAL
ME

Fig 2. Example of mobile app UI stylizations based on text intent, generated by Claude Design. Screenshot taken on 11.05.2026.

The blurring of professional standards via vibe coding opens the floodgates for naïve design, where the absence of an academic foundation becomes a source of radical sincerity rather than a defect. When stakeholders or developers generate interfaces directly, they ignore established rules that designers have been trained to follow for years. This creates an effect similar to the early internet, where the lack of templates led to the emergence of wild, often illogical, yet unique solutions. Unfortunately, researchers currently have limited access to the analysis of such works due to the effect of "digital decay" (Salyha, 2024). However, today this chaos collides with algorithmic conformism: vibe coding platforms, trained on mainstream libraries, attempt to force any bold request into the framework of correct modern design. A paradoxical struggle arises between the raw, unsystematized vision of the human and the machine's drive toward sterile standardization.

This situation will compel the professional design community to seek a new identity beyond mere functionality. When a machine can clone style, technical flawlessness ceases to be a hallmark of mastery. Designers find themselves in the position of Modernist artists who, following the invention of the daguerreotype, realized there was no point in competing with the camera in terms of realism. The response may manifest as "UI design impressionism" or the "UI avant-garde" — a conscious violation of rules and complex metaphors expressed through a visual language that AI cannot yet imitate, as it is rooted in irrational human experience rather than statistical probability. The professional must now do more than solve a user's problem; they must create a manifesto that cannot be confused with the faceless output of an AI.

If the mass market becomes saturated with cloned interfaces from vibe coders, the value of craft design might ascend to luxury status. We will likely witness a clear stratification of the digital space: on one side, utilitarian, machine-generated "fast-food" interfaces operating via predictable scenarios; on the other, complex, authored worlds created by humans. This will likely lead to design finally bifurcating into an engineering discipline — absorbed by vibe coding — and pure visual art, where the primary criterion of quality is not the convenience or usability, but the depth of intellectual and aesthetic resonance.

Conclusions

Vibe coding represents a fundamental shift in the UI design paradigm, transitioning the field from manual craft to a model of automated memetic evolution. By lowering the barrier to entry, this technology enables an explosion of stylistic variety and naïve design that challenges the long-standing homogenization of digital interfaces. However, the research demonstrates that while AI acts as a powerful catalyst for mutation and recombination, it lacks the critical discernment necessary to maintain professional standards independently.

A clear differentiation of products based on the criterion of design origin is occurring. Standardized interfaces produced via vibe coding are gradually monopolizing the mass-market segment. In this context, design acquires the characteristics of a utilitarian commodity with low added value, where operational speed and statistical alignment with average user expectations are prioritized. Such interfaces become homogeneous, as algorithms by their nature gravitate toward reproducing the most probable, and thus typical, combinations of existing patterns.

In response to the dominance of algorithmic conformism, professional design is undergoing an evolutionary shift toward authored authenticity and complex visual strategies. Master designers are forced to shift the focus of their activity into the realm of conceptual art and complex stylization to maintain market competitiveness and professional identity. This leads to the emergence of craft design — a premium segment where the uniqueness of the visual solution becomes a marker of the product's intellectual capital. Thus, vibe coding not only displaces humans from technical processes but

also provokes the diversification of interfaces, bifurcating the digital environment into a zone of functional standardization and a zone of high-variance professional creativity.

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BIOLOGICAL SCIENCES

ANNOTATION ON THE DISTRIBUTION OF PHYTOPATHOGENIC FUNGI IN FODDER PLANTS AND THEIR CHARACTERISTICS

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Abstract

The main geomorphological units of the Republic of Azerbaijan, the Greater Caucasus, the Lesser Caucasus (together with the Karabakh Plateau) and the Talysh Mountains, surround the Kur-Araz lowland from the north, west and southeast. The Nakhchivan Autonomous Republic is located within the middle reaches of the Araz River and the surrounding Zangezur and Daralayaz mountain ranges. Today, the agricultural sector has developed in all of these zones, and millions of tons of products are obtained annually through the cultivation of various cultivated plants.

Although the Republic of Azerbaijan is characterized as a territory with an important role for the agricultural sector, the agricultural sector is generally able to meet 50% of the needs of the country's population[6]. This once again proves the importance of increasing the efficiency of agricultural production, at least because meeting the needs of the majority of the country's population for agricultural products is considered one of the priorities of the country's agrarian policy.

Keywords: fodder crops, phytopathogenic fungi, physiological characteristics, agriculture

It should be noted that a decrease in yields in the agricultural sector can usually occur either due to changes in political and economic relations or due to the occurrence of various diseases. Therefore, it is important to always take into account the second reason for crop loss. Since the fight against such diseases within the borders of one country is not very effective today, that is, the pathologies caused by microorganisms do not know borders.

As a rule, an annotated list of fungi whose distribution is recorded as a result of mycological studies conducted in different scientific centers of the world in various aspects is compiled, and there is no universally accepted universal approach to compiling this list. Therefore, there are certain specific approaches to its compilation. However, the information provided by all in that list necessarily includes the current name of the fungus, the place where its distribution is recorded, and the substrate. Other information, such as the first occurrence of the fungus in the studied areas, its ecotrophic relationship and the manifestation of ecotrophic specialization, its relationship to substrates, as well as the characteristics of that fungus that are of interest from the point of view of practical needs, as well as the aspects in which it should be studied, is also included. It was considered appropriate to compile an annotated list of fungi used in the works of various authors in our research based on the following information:

1. The full name of the fungus (according to binary nomenclature and registration number in the BMA) and its current systematic affiliation as recorded on the BMA and Indexfungorum websites;

2. The place where the fungus was recorded, the substrates (plants) on which it was recorded in the studies and its biological status;

3. Its attitude to substrates and ecotrophic relationships and forms of manifestation of ecotrophic specialization;

4. The occurrence of the fungus in the world and in Azerbaijan and practical aspects of their use.

Here, one point should be clarified, which is also related to the synonyms of fungi. As is known, the systematics of fungi is currently a dynamically developing field of mycology. Sometimes the change between the main and synonymous species occurs so rapidly that its implementation does not remain stable even for a research period intended for 3-5 years. For this reason, in recent times, synonyms have not been shown in the annotated list of fungi. This approach was also used in our studies.

The number of species included in the Mucormycota (= Zygomycota) department and recorded in studies was 7, and there is no literature information about their causing any pathology, except for 1 species (Rhisobus stolonifera). In general, there is no literature information about species that cause serious damage to plants, including those of food importance, by causing various pathologies. At best, the names of fungi belonging to this department are mentioned in connection with their participation in mold processes, and it is not specified whether these plants are living or dead remains.

In general, these fungi do not have mobility in their life cycle, they have branched, large cells, but they are mostly unicellular but multinucleated. Other features, namely the presence of chitin and chitosan in the cell wall, the composition of the reserve nutrient glycogen, the fact that their reproduction occurs both sexually and asexually, the fact that the main part of their life activities take place in the haploid phase, etc. are common features inherent in fungi. According to

literature data, multicellular fungi are also found among the fungi belonging to this department [https://www.pesticidy.ru/Зигомикота], but such were not found among those recorded in our studies.

1. Absidia ramose (Zopf)Ledn [MB#221112].

From now on, the name of the fungus is Lichthemia ramosa (Zopf) Vuill [MB#416448]).

In studies, the fungus was found to be widespread in samples taken from the above-ground organs of plants such as Beta vulgaris, Hordeum vulgare, Panicum miliaceum and Triticum aestivum. It can be considered eurytrophic in terms of its relation to the substrate, since the plants in which it is found belong to both monocots and dicots. In addition, the fungus is found in all the studied geomorphological units.

In terms of ecotrophic relationships, it has characteristics typical of saprotrophs, and there is no literature information about its strong toxicity, as well as phytopathogenicity. A similar idea can be said about the practical use of the fungus.

It is possible to extract it into pure culture, and in studies this happened in the USSR. Its colony is light brown in color, its sporangia-bearings can be long, i.e. up to 700 μm, sometimes branched, its rhizoids are initially colorless, but later become light brown, its sporangia are pear-shaped or round, the diameter of the latter also varies between 30-65 μm. Its sporangispores are spherical and their diameter can be up to 5 μm. Chlamydospores are also produced, although in small numbers, and their diameter is between 10-12 μm. Sexual reproduction also occurs through zygogamy, and their zygaspores are spherical, with a maximum diameter of 185 μm. They are heterothallic. There is literature information about the distribution of the fungus in the world[1,8], including in Azerbaijan[6].

1. Mucor circinelloides Tiegh .[MB#198947].

In studies, the fungus was found in samples taken from aboveground vegetative and generative organs of plants such as Agrostis alba, Bromopsis inermis and Phleum pratense, and the fungus is included in the epiphytic mycobiota of plants. Thus, there is no literature information about its causing any pathology in plants. However, there is literature information about its belonging to opportunists, that is, causing certain pathologies in people with a weak immune system[2].

This fungus can also be considered eurytrophic in relation to the substrate, since the plants recorded in the studies belong to taxa that are somewhat distant from each other in terms of taxonomy.

The fact that the fungus belongs to saprotrophs has favorable indicators for its cultivation in pure culture, which is easier to understand in the AS. Thus, the colony it forms under these conditions has the ability to grow rapidly, and abundant sporulation occurs. Although the color of the colony is initially white, it then begins to take on a slightly grayish hue, its mycelia develop well and branch, but they do not have partitions. Rhizoids are not found.

There is no literature information about the toxigenicity of the fungus, and although there is no literature information about its carrying characteristics that lead to its use for practical purposes, there are research materials about the mushroom being promising in obtaining biodiesel and causing fatal diseases in people with weak immune systems[275].

The fungus has been previously recorded in studies conducted in Azerbaijan[6] and this situation has also been encountered in many countries of the world.

2. M.globosus Schreb[MB#433157]

During the studies, the fungus was found in samples taken from the above-ground vegetative organs of plants such as Beta vulgaris, Onobrychis viciaefolia, Trifolium pratense and Melilotus officinalis, and it was determined that it participates in the formation of the epiphytic mycobiota of the plant. It is not considered a substrate-specific fungus, that is, it has characteristics typical of eurytrophs, and the fact that it causes any pathology is not confirmed either in the course of studies or in the literature. A similar idea can be said about the toxigenicity of the fungus.

This fungus is easily cultured in SQM, which is associated with its saprotrophic lifestyle, and the colony it forms in such nutrient media does not show any signs that are different from those characteristic of the genus Mucor, that is, those noted in the determinants.

There is also no literature information on the practical use of the fungus, which is a result of its lack of extensive research.

This fungus is one of the species of mycobiota known to science in the nature of Azerbaijan[4,5], and there are literature data on its distribution in various parts of the world[1,3].

3. M. hiemalis Wehmer [MB#249401].

This fungus, which was found in samples taken from the above-ground organs of forage plants such as Agrostis alba, Medicago sativa, Lathyrus sativus and Trifolium repens, does not belong to phytopathogens, but there is literature data on its belonging to opportunists[2,7,9]. Like many species of this genus, this fungus is eurytrophic in relation to the substrate. Although it is found in all of the studied areas (KA, BQ, KQ and LA), it is not considered a dominant species.

Pure culture is possible in all of the SQM, which is due to the fact that the fungus leads a saprotrophic lifestyle. Both aerial and substrate mycelia participate in the formation of the colony, and the color of the colony formed by them together is grayish-brown. Due to the penetration of the substrate mycelium into the depths of the nutrient medium, no color change is observed in the reversum. The growth rate of the colony is high, the mycelium is well developed, but does not have partitions, and the process of sporulation occurs intensively. Its sporangia are ball-like, inside which numerous sporangiospores are formed. The shape of the latter also resembles an egg.

Conclusion: Fungi that spread in alfalfa and legume forage crops

Species belonging to the genus Fusarium (e.g. Fusarium oxysporum, F. solani): Causes fusarium wilt and root rot in plants. It is especially pathogenic in alfalfa (Medicago sativa) crops.

Peronospora viciae f. sp. pisi: Causes downy mildew. It causes a grayish-purple coating on the underside of the leaves.

Uromyces striatus: Causes alfalfa rust. It appears as brown pustules on the leaves and stems.

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FLORISTIC DIVERSITY AND STRUCTURAL FEATURES OF SUBALPINE MEADOW VEGETATION (ON THE EXAMPLE OF THE TALYSH REGION

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Abstract

The article studies the floristic composition, phytocenotic structure and ecological characteristics of the subalpine meadow vegetation of the Lerik and Yardimli regions, located in the high mountainous part of the Talysh mountain system. During the study, geobotanical descriptions were made of the Stipetum-Festucosum formations located at the foot of Mount Komurgoy in Lerik region and the Festuceta-Poaetum-Thymusosum formations distributed in the "Dere kecmez" summer pasture areas of Yardimli region.

As a result of the studies, it was determined that xerophyte and mesoxerophyte species predominate in both formations, which is associated with the harsh climatic conditions of the subalpine zone, intense solar radiation and relative humidity deficiency. Representatives of the Poaceae family were dominant in the studied phytocenoses. In particular, *Festuca ovina, Stipa transcaucasica, Stipa holocericea, Poa pratensis* and *Phleum pratense* species formed the main structure of the vegetation cover.

Among the shrubs and subshrubs, species belonging to the genus *Astracantha aurea, Acantholimon hohenackeri, Juniperus pygmaea* and *Thymus* are widespread. Perennial herbs predominated in terms of species diversity, while the presence of some mesophyte species was explained by the diversity of microrelief and soil-moisture conditions. During phenological observations, it was determined that most species were in the flowering phase, while legumes mainly entered the fruiting phase.

The total projected cover of the vegetation cover varied between 50–80%, and the stratification was mainly concentrated in the II and III tiers. The average height of the plants was recorded in the interval of 5–90 cm. The research results show that the subalpine meadows of Talysh, in addition to having high floristic richness, play an important ecological role in maintaining the stability of mountain ecosystems, preventing soil erosion and forming summer pasture resources.

The obtained materials can be used as a scientific basis for further research on the study of the geobotanical characteristics of the vegetation of the region, monitoring of subalpine grassland ecosystems and biodiversity conservation.

Keywords: subalpine grassland, geobotanical description, Talysh Mountains, floristic composition, xerophyte species, plant formation.

Introduction

Subalpine meadows are one of the richest and most dynamic vegetation types of mountain ecosystems, characterized by high biodiversity, complex phytocenotic structure and important ecological functions. These meadows are mainly located between the forest and alpine belts, creating a transition zone and are formed under the influence of various climatic, soil and relief factors. Subalpine vegetation is distinguished by both floristic richness and high productivity, playing an important role in protecting the ecological stability of mountain landscapes.

Subalpine meadows formed in the high mountainous areas of the Talysh mountain system have acquired unique floristic and phytocenotic characteristics as a result of the influence of specific natural and geographical conditions. The vertical zonation observed in the area, slopes with different exposures, heterogeneity of soil cover and humidity regime significantly affect the composition and structure of plant groups. As a result of the interaction of these factors, rich and complex phytocenoses with the participation of xerophyte, mesoxerophyte and mesophyte elements have formed here.

Subalpine meadows are also of great importance in terms of ecosystem services. This vegetation plays an important role in maintaining soil fertility, regulating surface flows, and preventing erosion and landslide processes. At the same time, subalpine pastures are considered one of the main fodder bases for livestock in the summer season and are one of the economically important natural resources of the region. In addition, these areas are of particular scientific importance in terms of protecting biodiversity as a habitat for many rare, endemic, and relict plant species.

In recent years, the increase in anthropogenic impacts, especially overgrazing, climate change, and land cover degradation, have created certain changes in the natural structure of subalpine ecosystems. In this regard, the study of the modern state of subalpine vegetation, the assessment of its floristic composition, and phytocenotic structure are considered to be one of the urgent scientific problems.

The study of plant formations distributed in the subalpine belt of Talish is of great importance in terms of the systematic study of the flora and vegetation of the region, geobotanical zoning, and ecological monitoring. The study of the geobotanical characteristics of subalpine meadows located in the high mountainous areas of Lerik and Yardimli regions allows us to determine the structure, dominant species, ecological groups and biomorphological characteristics of these ecosystems. The results obtained create a scientific basis for future research on the protection, efficient use and biodiversity conservation of subalpine pasture ecosystems.

Research object and methodology

The studies were conducted in the subalpine belt of Lerik and Yardimli districts, located in the high mountainous part of the Talysh mountain system. One of the research areas was a subalpine meadow located at an altitude of 2493 m above sea level in the territory of Lerik district, at the foot of Mount Komürgey. The other research area covered the "Derə qəməzmez" summer pasture areas of Yardimli district. Both areas are characterized by a complex relief structure, high humidity variability and diverse soil and plant cover.

Geobotanical descriptions in the research areas were carried out according to classical geobotanical methods. The floristic composition of plant groups was studied, the abundance of species, project cover, storey, life forms, ecological groups and phenological state were determined. During geobotanical descriptions, the degree of participation of each species in the phytocenosis and its dominance characteristics were taken into account.

The abundance of species was assessed with scores according to the Drude and Brown-Blanquet systems, and the storey of plants was analyzed in order to determine the vertical structure of the phytocenosis. The average height of plants was measured in centimeters and their location in different layers was determined. The percentage indicators of the project cover were used to assess the density and bioproductivity of the phytocenosis.

During the floristic analysis, the ecological groups of species were determined based on their relationship to humidity and temperature. For this purpose, the plants were mainly divided into xerophyte, mesoxerophyte and mesophyte groups. The results of the study showed that xerophyte and mesoxerophyte elements predominate in the subalpine zone, which is related to the climatic characteristics of the area.

The life forms of plants were grouped according to their biomorphological characteristics into shrubs, subshrubs, perennials, biennials and annual herbs. This division allowed us to determine the structural characteristics of phytocenoses and the distribution of dominant biomorphs. During phenological observations, the vegetation, flowering and fruiting stages of species were recorded.

Regional flora sources and systematic determinants were used to determine the species. As a result of a comparative analysis of the research materials, the floristic diversity, dominant species, and ecological characteristics of subalpine meadow formations were determined.

Results and discussion

Stipetum-Festucosum formation

The Stipetum-Festucosum formation recorded in the Lerik region developed mainly on grassy mountain-meadow soils. The formation is dominated by xerophytic species. Cereals such as *Festuca ovina, Stipa transcaucasica, Poa pratensis* and *Phleum pratense* occupy an important place in the floristic composition.

Among the shrubs, *Astracantha aurea, Acantholimon hohenackeri* and *Juniperus pygmaea species* are widespread. Among the semi-shrubs, *Thymus* kotschyanus is considered one of the dominant species. The species diversity of perennial grasses was higher, and mesoxerophytic and mesophytic elements were also found here.

Phenological observations showed that most species were in the flowering phase, and some legumes were in the legume stage. The total plant cover in the formation was 50–80% (Geobotanical description 1)

Geobotanical description 1

Species composition and structure of the Stipetum-Festucosum formation; Lerik district territory, subalpine zone. At the foot of Mount Kömürgey (2493 m above sea level) on grassy mountain-meadow soil

№	Biomorphological types	Ecological groups	Abundance (in points)	Total Design Cover (%)	Above-ground stratification and height (cm)
1	2	3	4	5	6
		Kollar			
1.	*Astracantha aurea* (Willd.) Podlich.	Xerophyte	1-2	II (25-40)	Flwr
2.	*Acantholimon hohenackeri* Jaub. et Spach. Boiss.	Xerophyte	1-2	III (20-30)	Flwr
3.	*Astracantha gutrathi* (Al.Teod., Fed. et Rzazade) Podlech.	Xerophyte	1	III (10-25)	Flwr
4.	Juniperus pygmaea C.Koch.	Xerophyte	1	III (10-20)	Vgtn
5.	Onobrychis cornuta (L.) Desv.	Xerophyte	1	III (5-15)	Frt
		Yarımkolcuq			
6.	Thymus kotschyanus Boiss. et Hohen.	Xerophyte	1-2	III (15-30)	Flwr
7.	Stachys inflata Benth.	Xerophyte	1	II (30-40)	Flwr
		Çoxillik otlar			
8.	Festuca ovina L.	Xerophyte	3-4	III (10-30)	Flwr
9.	Stipa transcaucasica Grossh.	Xerophyte	2-3	II (40-60)	Flwr
10	Poa pratensis L.	mesoxerophyte	1-2	III (20-30)	Flwr
11.	Phleum pratense L.	mesophyte	1-2	II (50-70)	Flwr
12.	Achillea millefolium L.	mesoxerophyte	1-2	II (40-60)	Flwr
13.	Helletorichon pratensis L.	Xerophyte	1-2	II (30-50)	Flwr
14.	Vicia truncatula Fisch.	mesoxerophyte	1-2	II (30-40)	Frt
15.	Alchimilla oxysepala Juz.	mesoxerophyte	1	II (50-80)	Flwr
16.	Stachus macrantha (C.Koch.) Stearn.	mesoxerophyte	1	II (40-70)	Flwr
17.	Anisantha riparia (Rehm.) Holub.	Xerophyte	1	II (30-50)	Flwr
18.	Teucrium orientale L.	Xerophyte	1	III (25-30)	Flwr
19.	Deschampsia caespitosa (L.)	mesophyte	1	III (20-25)	Flwr
20.	Festuca pratensis Huds.	mesophyte	1	III (15-20)	Flwr
21.	Poa meyeri Trin. ex Roshev.	mesophyte	1	III (10-20)	Flwr
22.	Trisetum rigidum (Bieb.) Roem. et Schult.	Xerophyte	1	III (10-15)	Flwr
23.	Plantago saxitalis Bieb.	mesoxerophyte	1	III (5-10)	Flwr
24.	Ranunculus caucasicus Bieb.	mesophyte	1	III (4-8)	Flwr
		İkillik otlar			
25.	Verbascum songaricum Schrenk.	mesophyte	1-2	II (30-50)	Flwr
26.	Carum carvi L.	mesophyte	1	II (30-50)	Flwr
		Birillik otlar			
27.	Bromus brizaformis Fisch. et C.A.Mey.	Xerophyte	1-2		Flwr
28.	Rumex retuculatus Boiss.	mesophyte	1		Vgtn
29.	Euphorbia hyrcana A.Grossh.	Xerophyte	1		Flwr.
The total project coverage is 50-80%.					

Festuceta-Poaetum-Thymusosum formation

In this formation, which is widespread in the "Dere geçmez" summer pasture areas of the Yardımlı region, the main dominant species were Festuca ovina, Stipa holocericea and Thymus trautvetteri. Although xerophytic elements predominated in the vegetation cover, the presence of mesophytic species was also observed.

Perennial grasses make up the main part of the floristic composition. Species such as Filipendula ulmaria, Dactylis glomerata, Koeleria cristata and Trifolium repens were recorded here. Anisantha tectorum and Lotus angustissimus are more widespread among annual grasses.

The plant layering was mainly concentrated in the II and III layers, the average height varied between 5–90 cm. The design cover was 50–80%, which indicates that subalpine meadows have a fairly dense vegetation cover. [Geobotanical description 2]

Geobotanical description 2

Species composition and structure of the Festuceta-Poaetum-Thymusosum formation; Yardimli district territory, "Der geçmez" summer pasture areas

№	Biomorphological types	Ecological groups	Abundance (in points)	Total Design Cover (%)	Above-ground stratification and height (cm)
1	2	3	4	5	6
Shrubs					
1.	*Acantholimon hohenackeri* Jaub. et Spach. Boiss.	Xerophyte	1-2	III (20-30)	Flwr
2.	*Astracantha aurea* (Willd.) Podlich.	Xerophyte	1	II (15-30)	Flwr
3.	*Astragalus euoplus* Trautv.	Xerophyte	1-2	III (20-30)	Frt
Subshrubs					
4.	*Thymus trautvetteri* Klok. et Shost.	Xerophyte	3-4	III (10-20)	Flwr
5.	*Achillea vermicularia* Trin.	Xerophyte	1-2	II (30-50)	Flwr
Perennial herbs					
6.	*Poa meyeri* Trin. ex Roshen.	mesophyte	1	II (30-40)	Flwr
7.	*Festuca ovina* L.	Xerophyte	3-4	III (10-20)	Flwr
8.	*Stipa holocericea* Trin. et Rupr.	Xerophyte	2-3	II (30-60)	Flwr
9.	*Onobrycis altissima* Grossh.	mesophyte	1-2	II (30-50)	Frt
10	*Filipendula ulmaria* (L.) Maxum.	mesophyte	1	III (70-90)	Flwr
11.	*Elytrygia trichophora* (Link.) Gould. Shinnere.	Xerophyte	1	II (40-60)	Flwr
12.	*Bromopsis variegata* (Bib.)	Xerophyte	1	III (30-50)	Flwr
13.	*Koeleria cristata* (L.) Pers.	Xerophyte	1	II (30-40)	Flwr
14.	*Alchimilla sericata* Reichenb. ex Bus.	Xerophyte	1	III (25-30)	Flwr
15.	*Dactylus glomerata* L.	Mesoxerophyte	1	III (20-25)	Flwr
16.	*Alopecurus glacialis* C.Koch.	Mesoxerophyte	1	III (15-20)	Flwr
17.	*Trifolium repens* (L.) Presl.	Xerophyte	1	III (10-15)	Frt
18.	*Colpodium versicolor* (Stev.)	Xerophyte	1	III (5-10)	Flwr
19.	*Taraxacum montanum* (C.A.Mey.) DC.	Xerophyte	1	III (4-8)	Flwr
20.	*Hieracium multisetum* Nalg. et Peter.	mesophyte	1	III (3-7)	Flwr
21.	*Potentilla bifursa* L.	Xerophyte	1	III (2-6)	Flwr
22.	*Dianthus talyschensis* Boiss.	Xerophyte	1	III (2-4)	Vgtn
Annual herbs					
23.	*Anisantha tectorum* (L.) Nevski.	Xerophyte	1-2	III (20-30)	Flwr
24.	*Lotus angustissimus* L.	mesophyte	1-2	III (10-20)	Flwr
25.	*Vicia hyrcanica* Fisch. et C.A.Mey.	Xerophyte	1	III (5-15)	Frt
The total project coverage is 50-80%.					

Conclusion

The conducted studies show that the subalpine meadow formations widespread in the high mountainous areas of Talysh have a rich floristic composition and a complex phytocenotic structure. The predominance of xerophyte and mesoxerophyte species in the studied formations is an indicator of adaptation to the climatic and soil conditions of the area. The fact that most of the dominant species belong to the cereal family indicates that this group plays an important role in the formation of subalpine pasture ecosystems.

These plant groups are of great importance in terms of protecting biodiversity, maintaining summer pasture resources and ensuring the stability of mountain ecosystems.

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CHEMICAL SCIENCES

SYNTHESIS AND STUDY OF CADMIUM THIOARSENITE AND THIOARSENATE COMPOUNDS BY HYDROCHEMICAL METHOD

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Abstract

This study presents the study of the conditions for the preparation of cadmium thioarsenite and thioarsenate compounds by the hydrochemical method. The aim is to synthesize new compounds in the cadmium arsenic-sulfide system and determine their crystal structure, thermal stability, and optical-electrical properties. Cadmium thioarsenite and thioarsenate compounds can be successfully synthesized by the hydrochemical method. These compounds exhibit similar properties to copper thioarsenates in terms of thermal stability, but the degree of crystallinity and morphological structure vary depending on the synthesis conditions. Initial assessments have shown that they have optical and electrical properties typical of semiconductor materials. The advantages of the hydrochemical method - low-temperature synthesis, simple technological process, and high purity - have proven themselves in the preparation of cadmium arsenic compounds. However, there are also limitations of the method: the degree of crystallinity and morphological properties of the precipitates vary depending on the synthesis conditions. Overall, the study shows that cadmium thioarsenite and thioarsenate compounds are promising for the preparation of new functional materials. In future work, it is advisable to study the physicochemical properties of these compounds in a wider range and test their application possibilities in optoelectronics and thermoelectric devices.

Keywords: Cadmium thioarsenite, crystal structure, thermal analysis, X-ray diffraction analysis

INTRODUCTION: Cadmium arsenic compounds are one of the systems of particular interest in modern chemistry and materials science. These compounds are important both theoretically and practically, because their crystal structure, electronic structure and physicochemical properties allow the preparation of new functional materials.[1]

In particular, cadmium compounds of the thioarsenite and thioarsenate types can have semiconducting properties and therefore have application prospects in the fields of optoelectronics, thermoelectric devices, sensor technologies and photochemistry. Traditional synthesis methods, especially high-temperature processes, have been widely used to obtain cadmium arsenic compounds. However, the main disadvantages of these methods - high energy consumption, difficulties in controlling the crystal structure and low product purity - have necessitated the search for alternative methods. The hydrochemical method is considered more convenient in this regard. The advantage of this method is that the reactions are carried out at relatively low temperatures, under simple laboratory conditions and, as a result, compounds of high purity are obtained.[2]

The successful application of the hydrochemical method in the synthesis of thioarsenate compounds based on arsenic(V) has already been confirmed by studies conducted on copper and other d-metals. For example, the preparation of copper(I) tetrathioarsenate by the hydrochemical method and the study of its crystal structure are among the important results in this field. These works serve as a methodological basis for the synthesis of analogous compounds in the cadmium arsenic-sulfide system. The study of cadmium thioarsenite and thioarsenate compounds is relevant both in terms of fundamental chemistry and applied materials science.[3]

The study of the crystal structure, thermal stability and optical-electrical properties of these compounds opens up new possibilities for their use as semiconductor materials. Thus, the purpose of this article is to study the conditions for the preparation of cadmium thioarsenite and thioarsenate compounds by the hydrochemical method, to analyze their structure and properties, and to determine the prospects for future applications.

EXPERIMENTAL PART: The experimental part of this study is devoted to a systematic study of the conditions for obtaining cadmium thioarsenite and thioarsenate compounds by the hydrochemical method. The aim of the work is to ensure the formation of new compounds in the Cd–As–S system as a result of the interaction of various reagents and to analyze their structure using modern analytical methods.[5]

Cadmium chloride ($CdCl_2 \cdot 2H_2O$) and cadmium sulfate ($CdSO_4 \cdot 8/3H_2O$) were taken in analytical purity. Sodium arsenate ($Na_3AsO_4 \cdot 12H_2O$) crystals were dissolved in distilled water. Sodium sulfide ($Na_2S \cdot 9H_2O$) solution was prepared in an inert atmosphere so that oxidation did not occur. The reactions were carried out under neutral and weakly alkaline pH conditions (6.5–8.0). The pH indicator was precisely controlled by a pH meter. 0.1 M solutions of cadmium salts were prepared. Arsenate and sulfide solutions were prepared separately and added dropwise to the cadmium solution. The mixing was carried out in a homogeneous environment using a magnetic stirrer. The reaction kinetics were studied by varying the temperature in the range of 20–80 °C. The resulting Cd–As–S precipitates were separated, washed in distilled water, and dried at 60–70 °C. [7]

RESULT: The conducted studies show that the synthesis of cadmium thioarsenite and thioarsenate compounds by the hydrochemical method is possible,

and this method has a number of advantages. The hydrochemical method allows obtaining products at low temperatures, in simple laboratory conditions and with high purity. Experiments have proven that as a result of changing the synthesis conditions - especially pH and temperature - different crystalline phases are formed: thioarsenites prevail in a neutral environment, and thioarsenates in a weakly alkaline environment. Analytical studies (XRF, DTA, QS, SEM) confirmed the crystal structure, thermal stability, the presence of arsenic-sulfide bonds and morphological characteristics of the precipitates. The results show that cadmium arsenic-sulfide compounds have optical and electrical properties characteristic of semiconductor materials. This opens up broad prospects for their application in optoelectronics, thermoelectric devices and sensor technologies. In general, the hydrochemical method is an effective approach for obtaining cadmium thioarsenite and thioarsenate compounds. In future research, it is considered appropriate to study the physicochemical properties of these compounds in a wider range, test their practical application possibilities, and develop new functional materials.

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ECONOMIC SCIENCES

THE ROLE OF INNOVATION ACTIVITY IN ENHANCING THE COMPETITIVENESS OF TOURISM IN THE NAKHCHIVAN AUTONOMOUS REPUBLİC

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Abstract

The article examines the role of innovation activity in enhancing the competitiveness of the tourism business in the Nakhchivan Autonomous Republic. Under modern conditions, achieving a competitive advantage in the tourism sector is closely associated with the implementation of new technologies, the improvement of service quality, the use of digital solutions, and the efficient utilization of local resources. The Nakhchivan Autonomous Republic possesses rich natural, historical, and cultural tourism potential, creating favorable opportunities for the development of innovative tourism activities. Tourism resources in the region, such as Duzdag Physiotherapy Center, Ashabi-Kahf Shrine, Momine Khatun Mausoleum, and mineral water sources, can be marketed more effectively through innovative approaches. The research demonstrates that the implementation of innovation strategies in tourism enterprises, the development of digital marketing, the expansion of online reservation systems, and the personalization of services significantly enhance the competitiveness of the region's tourism sector. At the same time, innovation activity has an important impact on reducing tourism seasonality, increasing investment attractiveness, creating new jobs, and accelerating regional socio-economic development.

Keywords: tourism business, innovation activity, competitive advantage, digital transformation, tourism infrastructure, regional development.

INTRODUCTION

In the Republic of Azerbaijan, one of the priority areas identified for the development of the non-oil sector is the tourism sector. Tourism, with its multifaceted economic and social impacts, plays an important role in ensuring the country's sustainable development, increasing regional economic activity, and providing employment for the population (1, p. 12; 2, p. 45; 8, p. 27). Considering its historical development process, it becomes clear that tourism has held an important place in the economic systems of various countries since ancient times, and in the modern era it has become one of the fastest-growing sectors of the global economy. This sector not only contributes to the formation of budget revenues but also has a significant impact on the expansion of investment flows, the modernization of infrastructure, and the socio-economic development of regions (1, p. 34; 8, p. 73).

In recent years, economic reforms implemented in the Republic of Azerbaijan, state support mechanisms, and strategic documents adopted in the field of tourism have created broad opportunities for the more efficient utilization of the country's tourism potential. In this regard, the development of regional tourism opportunities is of particular importance. The Nakhchivan Autonomous Republic is one of the most promising tourism regions of Azerbaijan, with its rich natural resources, favorable climatic conditions, ancient historical and cultural heritage, and modern tourism infrastructure (5, p. 22; 6; 8, p. 219). The region possesses tourism resources such as the Duzdag Physiotherapy Center, Ashabi-Kahf Shrine, Momine Khatun Mausoleum, as well as mineral water sources like Sirab, Badamli, and Vaykhir, which can be transformed into higher competitive advantages through innovative approaches.

The main factors determining the development of tourism in the Nakhchivan Autonomous Republic are as follows (1, p. 78; 5, p. 145; 8, p. 241):

- • continuous provision of state support through diversified and multifaceted mechanisms;
- • the formation of new tourism directions and destinations;
- • the restoration of historical and cultural monuments and their utilization for tourism purposes;
- modernization of transport and road infrastructure;
- the development of accommodation and public catering facilities in terms of both quantity and quality;
- the expansion of the activities of health and recreational centers;
- the organization of tourist routes and the improvement of service quality;
- the application of digital technologies and innovative management methods.

In the modern economic environment, the success of the tourism business is determined not only by available resources but also by the level of innovation activity. Innovation increases the competitiveness of tourism enterprises through the creation of new products and services, the implementation of digital solutions, the personalization of services, the improvement of marketing strategies, and the optimization of management processes. In particular, online reservation systems, digital marketing, virtual

tours, artificial intelligence-based customer services, and data analytics have become key competitive tools in contemporary tourism business (1, p. 121).

The development of innovation activity in the tourism business creates multifaceted benefits for the regional economy (2, p. 331; 8, p. 356). These benefits can be summarized as follows:

- the enhancement of the competitiveness of tourism enterprises;
- the increase in tourist flows and the expansion of service exports;
- the creation of new jobs and the increase in population employment;
- • the development of local entrepreneurship and family businesses;
- the strengthening of investment attractiveness;
- the reduction of seasonal dependency;
- the formation of a regional brand;
- the acceleration of socio-economic development.

Thus, innovation activity acts as one of the key determinants in the formation of competitive advantages in the tourism business. The rich tourism potential and existing infrastructure opportunities of the Nakhchivan Autonomous Republic create broad prospects for the application of innovative approaches (N Bababayli et al., 2025). In this regard, the study of the role of innovation processes in enhancing the competitiveness of the tourism business is of both scientific and practical importance.

INNOVATION POTENTIAL AND THE FORMATION OF COMPETITIVE ADVANTAGES OF THE TOURISM BUSINESS IN THE NAKHCHIVAN AUTONOMOUS REPUBLIC

The formation and development of the tourism sector in Azerbaijan have rich historical traditions. The natural resources, favorable climatic conditions, rich historical and cultural heritage, and targeted development policies implemented by the state across different regions of the country have contributed to tourism becoming one of the priority sectors of the national economy. In this regard, the Nakhchivan Autonomous Republic holds particular importance. The region's strategic geographical location, unique natural resources, mineral waters with therapeutic value, historical monuments, and modern infrastructure create favorable conditions for the innovative development of the tourism business (5, pp. 34–48; 6; 8, p. 214).Among the main factors influencing the development of the tourism sector in the Nakhchivan Autonomous Republic are the systematic nature of state support, the modernization of transport and communication infrastructure, the creation of tourism routes, the expansion of hotel and catering services, the protection of historical and cultural heritage, and the strengthening of international promotion activities. Tourism activity in the region is of strategic importance not only as a source of economic income but also in terms of increasing employment, developing local entrepreneurship, promoting national cultural values, and accelerating regional development (2, p. 311; 7, p. 94).

Innovation activity plays a decisive role in the formation of competitive advantage in the tourism business. Innovation strengthens the market position of enterprises through the creation of new products and services, the improvement of existing services, the optimization of management processes, and the application of digital technologies. As a result of this process, tourism enterprises gain the opportunity to differentiate themselves from competitors, increase customer satisfaction, reduce costs, and achieve more sustainable market advantages (A Jabbarov ; H Zeynalov ; R Aliyev. 2024).

The tourism potential of the Nakhchivan Autonomous Republic is highly extensive from an innovation perspective. Existing resources create broad opportunities for the development of various types of tourism, including health, religious, ecological, cultural, and recreational tourism. The presentation of these resources through innovative marketing strategies, branding, and digital platforms significantly enhances the region's competitiveness in the international tourism market (1, p. 126; 8, p. 342). At the same time, innovation activity also has a significant impact on reducing seasonality in tourism. In particular, health and medical tourism provide year-round services, thereby contributing to the stabilization of tourist flows and ensuring the sustainability of enterprises' revenues. This, in turn, increases investment attractiveness, leads to the creation of new jobs, and accelerates the socio-economic development of the region (Zeynalov, H. Ə. 2025)..

ENHANCING THE COMPETITIVENESS OF TOURISM ENTERPRISES BASED ON HEALTH TOURISM AND DIGITAL INNOVATION

The integration of innovation activity into the tourism business in the Nakhchivan Autonomous Republic is most clearly demonstrated in the example of health tourism. The Duzdag Physiotherapy Center is a successful model of innovative natural resource management and high-quality service organization in the region (Zeynalov, H. Ə. 2025). Through the application of speleotherapy methods, this center has become an internationally recognized tourism and treatment complex for the treatment of respiratory system diseases (3, pp. 4–6; 9). The nearby hotel and SPA infrastructure combines treatment, recreation, and leisure services into a single product, thereby creating an integrated tourism experience. Another important health tourism facility in the region is the Daridagh Arsenic Water Treatment Center, where various diseases are treated based on thermal arsenic-rich waters. Modern service infrastructure, the professionalism of medical staff, and the organization of additional services increase the competitive advantage of this facility in the market (Zeynalov, H. Ə. 2025). At the same time, mineral water sources in the Ashabi-Kahf area facilitate the integration of health and religious tourism, enabling the creation of new tourism products (5, pp. 118–121).

The industrial bottling of mineral water sources such as Sirab, Badamli, Vaykhir, and others, their presentation to the market as branded products, and their export contribute significantly to the formation of the region's tourism image. These products not only generate economic income but also serve to promote

the Nakhchivan Autonomous Republic as a health tourism destination (2, p. 338; 8, p. 349). In the modern era, the role of digital innovations in enhancing the competitiveness of the tourism business is particularly significant. Online reservation systems, digital marketing, social media platforms, virtual tours, customer relationship management systems, and data analytics have a direct impact on tourists' decision-making processes. Through these tools, tourism enterprises gain more effective access to target markets, maintain continuous communication with customers, and provide personalized services (1, p. 127; 8, p. 338). The conducted analysis shows that the systematic application of innovation activity improves service quality in tourism enterprises, increases tourist satisfaction, strengthens loyalty, and forms sustainable competitive advantages in the market. Consequently, the synergy between health tourism and digital technologies acts as one of the key strategic directions ensuring the more competitive development of the tourism sector of the Nakhchivan Autonomous Republic at the international level (1, p. 149; 3, p. 6; 8, p. 417).

CONCLUSION

Since ancient times, people have highly valued the important role of mineral waters, therapeutic salt deposits, and other natural resources in the protection and restoration of health. In the modern era, the integration of these resources with innovative management and marketing approaches has created new opportunities for the development of the tourism business.The conducted research shows that the Nakhchivan Autonomous Republic has significant potential for the development of innovation-based tourism business due to its rich natural healing resources, modern tourism infrastructure, and favorable geographical position. The Duzdag Physiotherapy Center, the Daridagh Arsenic Water Treatment Center, the Ashabi-Kahf mineral waters, Sirab, and Badamli constitute the main pillars of the region's competitive advantages.

Thus, the innovation process, as one of the key factors in the formation of competitive advantages in the tourism business, plays a strategic role in the efficient realization of the tourism potential of the Nakhchivan Autonomous Republic.

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COMPREHENSIVE ASSESSMENT OF FACTORS AFFECTING THE EFFECTIVENESS OF TOURISM SERVICES

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Abstract

This article examines the key factors affecting the effectiveness of tourism services under conditions of increasing global competition and digital transformation. The study analyzes the role of economic, technological, organizational, social, and environmental factors in improving tourism service performance and destination competitiveness. Particular attention is paid to the impact of digitalization, smart tourism technologies, infrastructure development, service quality management, and sustainability practices on tourism efficiency. The research also investigates recent positive transformations in the global tourism industry and tourism reforms implemented in Uzbekistan. Comparative statistical analysis and scientific literature review methods were applied to evaluate the relationship between tourism service effectiveness and tourism competitiveness. The findings indicate that the integration of innovative technologies, customer-oriented management systems, sustainable tourism models, and advanced digital infrastructure significantly enhances tourism productivity and tourist satisfaction. The study proposes practical recommendations aimed at improving tourism service effectiveness, strengthening tourism competitiveness, and ensuring sustainable tourism development in Uzbekistan.

Keywords: tourism services, tourism effectiveness, destination competitiveness, smart tourism, digital transformation, sustainable tourism, tourism infrastructure, service quality, tourism management, customer satisfaction.

In recent years, the tourism industry has become one of the most dynamic and strategically important sectors of the global economy. The rapid growth of international mobility, digital transformation, increasing competition among destinations, and changing consumer expectations have significantly intensified the need to improve the effectiveness of tourism services. Today, tourism service efficiency is no longer evaluated solely by the number of tourists or tourism revenues; instead, it is increasingly associated with service quality, customer satisfaction, innovation, sustainability, digitalization, infrastructure development, and institutional effectiveness.

The growing importance of tourism services is directly linked to their contribution to economic growth, employment generation, regional development, and foreign exchange earnings. In many countries, tourism acts as a catalyst for the development of transportation, hospitality, retail trade, entertainment, and digital service industries. Moreover, the post-pandemic transformation of the tourism market has accelerated the integration of smart technologies, artificial intelligence, sustainable management practices, and personalized customer-oriented services into tourism activities. Under such conditions, identifying and systematically evaluating the factors influencing tourism service effectiveness has become essential for enhancing destination competitiveness and ensuring sustainable tourism development.

Recent global statistics clearly demonstrate the increasing economic significance of tourism. According to the World Travel & Tourism Council, the global travel and tourism sector is expected to contribute approximately USD 11.7 trillion to the world economy in 2025, accounting for nearly 10.3% of global GDP. In addition, international visitor spending is forecast to reach a historic USD 2.1 trillion in 2025, while the sector is projected to support around 371 million jobs worldwide (WTTC, 2025). These indicators confirm that tourism services have become one of the leading drivers of global economic growth and competitiveness.

At the same time, the effectiveness of tourism services depends on numerous interrelated economic, social, technological, environmental, and institutional factors. In particular, the quality of tourism infrastructure, digital accessibility, service innovation, human capital, destination management, transportation systems, environmental sustainability, safety, and customer-oriented marketing strategies play a decisive role in improving tourism performance. Therefore, a comprehensive assessment approach is necessary to identify the most influential factors and develop effective management mechanisms for increasing tourism service efficiency.

For developing countries, including Uzbekistan, the issue of improving tourism service effectiveness has become especially relevant in the context of expanding international tourism flows and strengthening national tourism competitiveness. In recent years, Uzbekistan has implemented large-scale reforms aimed at modernizing tourism infrastructure, simplifying visa procedures, digitalizing tourism services, and increasing investment attractiveness in the tourism sector. However, achieving sustainable growth in tourism services requires a deeper scientific assessment of the factors influencing service effectiveness and the development of integrated evaluation mechanisms.

This study aims to provide a comprehensive assessment of the factors affecting the effectiveness of tourism services by analyzing their economic, organizational, technological, and social dimensions. The research also seeks to identify the key determinants influencing tourism service performance and propose prac-

tical recommendations for improving tourism management and service quality under conditions of increasing global competition.

The issue of improving the effectiveness of tourism services has become one of the central research topics in tourism economics and destination management studies. In the context of increasing global competition, digital transformation, and changing tourist behavior, many scholars have focused on identifying the key determinants influencing tourism service performance, customer satisfaction, and destination competitiveness. Existing scientific literature demonstrates that tourism service effectiveness is a multidimensional concept that depends on economic, technological, institutional, social, environmental, and managerial factors.

One of the most influential contributions to tourism competitiveness studies was made by Larry Dwyer and Chulwon Kim, who developed an integrated destination competitiveness model. According to their research, tourism service effectiveness is strongly influenced by infrastructure quality, destination management efficiency, price competitiveness, and government support policies. The authors emphasized that tourism competitiveness should be assessed through both quantitative and qualitative indicators, including tourist satisfaction and service innovation (Dwyer and Kim, 2003).

Similarly, J. R. Brent Ritchie and Geoffrey Crouch argued that destination competitiveness and tourism service efficiency are closely connected to strategic planning, human resource development, environmental sustainability, and the ability of destinations to create memorable tourist experiences. Their conceptual model became one of the foundational frameworks for evaluating tourism performance in international tourism studies (Ritchie and Crouch, 2003).

Research conducted by Parasuraman, Valarie Zeithaml, and Leonard Berry introduced the SERVQUAL model, which remains one of the most widely applied approaches for measuring service quality in tourism and hospitality industries. Their studies demonstrated that reliability, responsiveness, assurance, empathy, and tangibility are critical dimensions determining customer perceptions of tourism service effectiveness (Parasuraman et al., 1988).

In recent years, digital transformation has become a major focus in tourism effectiveness studies. Dimitrios Buhalis highlighted the growing role of smart technologies, artificial intelligence, and digital ecosystems in improving tourism service efficiency. According to the author, digitalization enables destinations and tourism enterprises to optimize service delivery, personalize tourist experiences, and enhance operational efficiency through real-time data management and smart tourism systems (Buhalis and Amaranggana, 2015).

The sustainability dimension of tourism effectiveness has also attracted considerable academic attention. C. Michael Hall emphasized that tourism service effectiveness should not be assessed solely through economic indicators but also through environmental and socio-cultural sustainability criteria. The author argued that long-term tourism competitiveness depends on balancing economic benefits with ecological preservation and local community well-being (Hall, 2019).

From the perspective of tourism economics, Larry Dwyer and Peter Forsyth examined the economic efficiency of tourism destinations by analyzing tourism yield, productivity, and value-added generation. Their studies demonstrated that tourism service effectiveness significantly affects regional economic growth, employment generation, and foreign exchange earnings (Dwyer and Forsyth, 2011).

In Uzbekistan, scientific studies related to tourism service effectiveness have mainly focused on tourism competitiveness, infrastructure development, and digital transformation in tourism management. Qahramon Abdurakhmonov analyzed the relationship between human capital development and service sector productivity, emphasizing that the quality of labor resources and professional competencies directly influence tourism service efficiency. Meanwhile, Saidmurod Gulomov studied the role of digital technologies and innovative management systems in improving service effectiveness within the tourism sector. Their studies indicate that digital transformation, service standardization, and institutional reforms are essential factors for enhancing tourism competitiveness in Uzbekistan.

Despite the significant number of studies devoted to tourism effectiveness, existing literature still demonstrates several research gaps. Most previous studies focus either on tourism competitiveness or customer satisfaction separately, while comprehensive multidimensional assessment mechanisms integrating economic, technological, institutional, environmental, and social indicators remain insufficiently developed. Furthermore, there is limited research on developing integrated evaluation models specifically adapted to emerging tourism destinations such as Uzbekistan. Therefore, the present study seeks to contribute to the existing literature by providing a comprehensive assessment framework for evaluating the factors affecting tourism service effectiveness.

In recent years, the global tourism industry has undergone significant structural and technological transformations aimed at improving the effectiveness of tourism services. The rapid development of digital technologies, increasing competition among destinations, growing demand for personalized travel experiences, and the transition toward sustainable tourism models have forced tourism enterprises and governments to adopt innovative management approaches. As a result, tourism service effectiveness is increasingly being assessed not only through tourist arrivals and revenues but also through service quality, operational efficiency, customer satisfaction, digital accessibility, environmental sustainability, and long-term destination competitiveness.

One of the most notable global changes in tourism service management has been the accelerated digitalization of tourism activities. Today, many countries actively implement smart tourism technologies, artificial intelligence, big data analytics, blockchain systems, and digital customer relationship management (CRM) platforms to optimize tourism services. Smart tourism destinations such as Singapore, Dubai, and Barcelona

have successfully integrated digital ecosystems into tourism management. These systems enable real-time tourist flow monitoring, personalized service recommendations, digital ticketing, and intelligent transportation management. Such innovations significantly increase tourism service efficiency by reducing operational costs, improving tourist satisfaction, and enhancing resource utilization.

Another important global trend is the growing focus on sustainable tourism development. In many developed countries, tourism effectiveness is increasingly associated with environmental protection, carbon reduction, and social inclusiveness. For example, Scandinavian countries actively promote green tourism models based on renewable energy, eco-certification systems, and sustainable destination management practices. Similarly, the European Union has expanded support for sustainable tourism projects through digital innovation funds and environmental tourism initiatives. These measures demonstrate that modern tourism competitiveness depends not only on economic performance but also on ecological and social sustainability indicators.

The hospitality industry has also experienced substantial improvements in service effectiveness due to technological innovation. International hotel chains such as Marriott International, Hilton Worldwide, and Accor increasingly utilize artificial intelligence, automated reservation systems, smart room technologies, and customer data analytics to enhance service quality and operational productivity. These technologies allow tourism enterprises to optimize labor costs, improve customer experience, and strengthen market competitiveness.

In addition, the integration of artificial intelligence into tourism services has become one of the most significant innovations in recent years. AI-powered chatbots, virtual assistants, recommendation systems, and predictive analytics are now widely used in tourism management and marketing. According to international industry reports, tourism enterprises implementing AI-based customer service systems have achieved higher customer satisfaction levels and increased operational efficiency. The use of big data analytics also enables tourism organizations to predict tourist behavior, manage tourism demand, and improve strategic decision-making processes.

The global tourism sector has also increasingly focused on experience-based tourism models. Modern tourists are no longer satisfied with standard tourism packages and increasingly demand personalized, authentic, and emotionally engaging experiences. As a result, tourism destinations are actively developing cultural tourism, gastronomic tourism, medical tourism, educational tourism, and eco-tourism services. This diversification contributes to increasing tourism service effectiveness by extending tourist stay duration, increasing tourist spending, and improving destination loyalty.

Positive changes can also be observed in developing countries, particularly in Central Asia. In recent years, countries such as Kazakhstan, Uzbekistan, and Kyrgyzstan have intensified reforms aimed at modernizing tourism infrastructure and increasing tourism competitiveness. Among these countries, Uzbekistan has demonstrated particularly rapid progress in tourism sector transformation.

In Uzbekistan, large-scale reforms have been implemented to improve tourism service effectiveness and strengthen the country's position in the international tourism market. The government has adopted several strategic programs focused on tourism infrastructure modernization, simplification of visa procedures, digitalization of tourism services, and attraction of foreign investment into the tourism sector. The introduction of visa-free and simplified visa regimes for citizens of numerous countries significantly increased international tourist arrivals and improved the accessibility of tourism services.

One of the most important reforms in Uzbekistan has been the digital transformation of tourism management systems. Online hotel registration systems, electronic visa platforms, digital tourism portals, and integrated booking services have significantly improved service accessibility and operational efficiency. The development of digital tourism ecosystems has simplified communication between tourists, tourism enterprises, and government institutions. In addition, Uzbekistan has actively promoted its tourism potential through international tourism exhibitions, digital marketing campaigns, and cooperation with global tourism organizations.

Significant improvements have also been made in tourism infrastructure development. Modern hotels, transport systems, airports, cultural tourism complexes, and recreational facilities have been constructed or renovated in major tourism destinations such as Samarkand, Bukhara, and Khiva. In particular, the establishment of the Silk Road Samarkand international tourism center became one of the largest tourism infrastructure projects in Central Asia. The project significantly expanded Uzbekistan's capacity to host international forums, exhibitions, and large-scale tourism events.

Another positive transformation in Uzbekistan concerns the diversification of tourism services. The country has expanded its tourism products beyond traditional cultural tourism by developing pilgrimage tourism, eco-tourism, gastronomic tourism, medical tourism, and educational tourism. Such diversification improves tourism service effectiveness by attracting different tourist segments and increasing tourism revenues throughout the year.

Human capital development has also become an important direction of tourism reforms in Uzbekistan. Tourism education programs, professional training centers, and international academic cooperation projects have expanded significantly in recent years. Universities and tourism training institutions increasingly integrate international educational standards, digital competencies, and foreign language programs into tourism education. This contributes to improving workforce quality and enhancing service professionalism in the tourism sector.

Moreover, the country has intensified efforts to improve international tourism branding and destination

competitiveness. Uzbekistan's historical and cultural heritage, especially the tourism potential of the Great Silk Road cities, has been actively promoted in international tourism markets. International tourism forums, investment conferences, and cultural festivals organized in Uzbekistan have strengthened the country's tourism image globally.

Despite these positive developments, several challenges still remain in improving tourism service effectiveness both globally and in Uzbekistan. These include uneven infrastructure development, shortage of highly qualified personnel, environmental sustainability concerns, and the need for deeper digital integration. Nevertheless, current reforms and modernization processes indicate that tourism services are becoming increasingly innovative, customer-oriented, and technologically advanced. The ongoing transformations in global and national tourism systems demonstrate that improving tourism service effectiveness has become one of the key strategic priorities for ensuring sustainable economic growth and international competitiveness.

The effectiveness of tourism services is closely associated with the ability of destinations to generate economic value, attract international visitors, improve tourist satisfaction, and create employment opportunities. In recent years, global tourism recovery after the pandemic period has accelerated investments in tourism infrastructure, digital technologies, and service quality improvement. As a result, many countries have achieved substantial growth in tourism revenues and tourism-related employment, which directly reflects improvements in tourism service effectiveness. Comparative analysis of global tourism indicators provides an opportunity to evaluate the relationship between tourist flows, economic contribution, and service efficiency.

Table 1

Key Global Indicators Reflecting the Effectiveness of Tourism Services in 2025

Country / Region	International Tourist Arrivals (million)	Tourism Contribution to GDP (%)	International Tourism Receipts (USD billion)	Tourism Employment Share (%)	Main Effectiveness Drivers
France	102	9.1	71	8.8	High-quality infrastructure, cultural tourism, digital services
Spain	94	12.8	92	13.0	Smart tourism systems, sustainable tourism policies
Turkey	62	12.0	61	10.2	Competitive prices, digital marketing, diversified tourism
United Arab Emirates	31	11.7	51	9.8	Luxury tourism, AI integration, aviation connectivity
Singapore	16	9.7	29	8.1	Smart destination technologies, innovation-driven services
Uzbekistan	11.2	3.4	2.7	2.9	Visa liberalization, cultural tourism, infrastructure reforms

Source: Compiled by the author based on data from the World Travel & Tourism Council (WTTC), UN Tourism (UNWTO), and the Statistics Agency of Uzbekistan

The data presented in the table demonstrate that tourism service effectiveness is strongly influenced by the integration of innovation, infrastructure quality, digital transformation, and destination management systems. Countries such as Spain and France maintain global leadership not only because of high tourist arrivals but also due to their advanced tourism ecosystems, sustainable management approaches, and customer-oriented service models. In particular, Spain's tourism sector contributes nearly 13% of national GDP, reflecting the high productivity and effectiveness of its tourism services.

Turkey demonstrates one of the most successful examples among emerging tourism economies. The country has significantly improved tourism service effectiveness through aggressive international marketing campaigns, diversified tourism products, digital reservation systems, and competitive pricing strategies. Tourism revenues exceeding USD 60 billion indicate the strong economic efficiency of tourism services in the country.

Meanwhile, Singapore and United Arab Emirates illustrate the growing importance of smart tourism technologies and innovation-based tourism management. Their success is largely associated with artificial intelligence integration, digital tourism ecosystems, and high-quality tourism infrastructure.

The indicators for Uzbekistan also reflect positive transformation trends in recent years. The increase in international tourist arrivals and tourism revenues demonstrates the effectiveness of ongoing reforms re-

lated to visa liberalization, infrastructure modernization, and tourism diversification. However, compared to leading tourism destinations, the contribution of tourism to GDP and employment remains relatively low, indicating substantial untapped potential for improving tourism service effectiveness. The comparative analysis confirms that the effectiveness of tourism services depends on a combination of technological innovation, institutional support, infrastructure quality, service diversification, and sustainable destination management. Countries that successfully integrate these components achieve higher tourism competitiveness, stronger economic performance, and greater resilience in the global tourism market.

The conducted research demonstrates that the effectiveness of tourism services has become one of the key determinants of tourism competitiveness and sustainable economic development in the modern global economy. In the context of increasing international competition, rapid digital transformation, and changing tourist expectations, tourism service effectiveness is no longer limited to traditional indicators such as tourist arrivals and tourism revenues. Instead, it increasingly depends on service quality, technological innovation, customer satisfaction, infrastructure development, sustainability practices, institutional efficiency, and destination management systems.

The analysis revealed that countries with highly developed tourism sectors achieve strong economic performance primarily through the integration of smart technologies, digital tourism ecosystems, innovative marketing strategies, and diversified tourism products. The experiences of countries such as Spain, France, Turkey, and Singapore demonstrate that tourism effectiveness is closely linked to strategic planning, investment in tourism infrastructure, and the implementation of customer-oriented management models. In particular, the application of artificial intelligence, big data analytics, and smart tourism technologies has significantly improved operational efficiency and tourist satisfaction in many destinations.

The study also indicates that sustainable tourism development has become an essential component of tourism service effectiveness. Modern tourism competitiveness increasingly depends on balancing economic growth with environmental sustainability, social inclusiveness, and cultural preservation. Therefore, destinations that successfully integrate sustainability principles into tourism management systems gain long-term competitive advantages in the global tourism market.

In the case of Uzbekistan, the research confirms that substantial progress has been achieved in recent years through tourism reforms, infrastructure modernization, visa liberalization, and digital transformation initiatives. The increase in tourist arrivals, expansion of tourism services, and growing international recognition of Uzbekistan's tourism potential reflect the positive outcomes of these reforms. However, several structural challenges still limit the overall effectiveness of tourism services, including insufficient digital integration, uneven infrastructure quality, limited service standardization, shortage of highly qualified personnel, and relatively weak international tourism branding mechanisms.

Based on the findings of the study, the following recommendations are proposed to improve the effectiveness of tourism services:

– to develop integrated smart tourism management systems based on artificial intelligence, digital platforms, and real-time tourism analytics;

– to strengthen service quality management through the implementation of international tourism service standards and certification systems;

– to improve tourism infrastructure, especially transportation, accommodation, and digital accessibility in regional tourism destinations;

– to enhance professional training systems and human capital development in tourism management, hospitality, and digital tourism services;

– to expand sustainable tourism practices aimed at environmental protection, cultural heritage preservation, and efficient resource utilization;

– to increase investment attractiveness in tourism through public-private partnership mechanisms and innovation-oriented tourism projects;

– to strengthen international tourism marketing strategies and promote Uzbekistan's tourism brand through digital media and global tourism exhibitions;

– to diversify tourism products by expanding ecotourism, medical tourism, gastronomic tourism, pilgrimage tourism, and educational tourism services;

– to improve customer-oriented tourism management systems focused on tourist satisfaction, personalized experiences, and service innovation.

In conclusion, the effectiveness of tourism services should be considered a multidimensional strategic indicator reflecting the overall competitiveness and sustainability of tourism destinations. The successful integration of digital technologies, innovative management approaches, sustainability principles, and customer-oriented services creates significant opportunities for enhancing tourism productivity and economic contribution. For Uzbekistan, improving tourism service effectiveness can become one of the major drivers of long-term economic growth, international competitiveness, and regional tourism leadership in Central Asia.

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JURISPRUDENCE

A CRIMINAL LAW PERSPECTIVE ON MONEY LAUNDERING AS AN INSTRUMENT OF ORGANISED CRIME

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Abstract

Money laundering constitutes a specific form of financial crime that is intrinsically linked to organized crime. It is commonly understood as a highly complex process through which proceeds derived from criminal activity are concealed, transformed and subsequently integrated into the apparently lawful economy. This mechanism is not merely a consequence of organised crime, but rather one of the essential pillars that enables its survival, expansion and consolidation. The large-scale concealment of criminal assets through their injection into the formal economy produces serious adverse effects on financial transparency, fair competition and public security, while at the same time revealing the economic capacity and operational power of organised criminal structures. For this reason, every State considers money laundering a serious challenge, closely connected to the fight against organised crime and to the protection of the economic and legal order.

In many countries, money laundering has evolved into a mechanism closely intertwined with the most sophisticated forms of organised crime, including drug trafficking, corruption, tax evasion, smuggling and trafficking in human beings. These criminal activities generate substantial illicit proceeds which subsequently need to be channelled into the legitimate financial system. The growing strength of organised crime, accompanied by the continuous process of money laundering, entails increased criminal activity, unlawful profits, corruption and impunity.

States have adopted legislative measures initially defined under the Vienna Convention, the Palermo Convention and subsequently the Warsaw Convention, with a view to criminalizing the laundering of proceeds derived from organized crime and other criminal sources, tracing, seizing and confiscating illicit assets, including those used for the financing of terrorism, as well as introducing preventive and financial control measures. In Albania, these conventions constitute binding international legal guidance for anti-corruption bodies and for the investigation and adjudication of organized crime. They also form the basis for the implementation of domestic legislation, particularly Law No. 10192/2009 "On preventing and combating organized crime, trafficking and corruption through preventive measures against assets", as amended, Law No. 9917/2008 "On the prevention of money laundering and terrorist financing", as amended, Article 287 of the Criminal Code, the legislation on extradition and mutual legal assistance, as well as the cooperation of SPAK with international partners such as Europol, Interpol, Eurojust, MONEYVAL and others.

A distinctive feature of this criminal offence is that criminal investigation may proceed independently, even where the investigation of the predicate or initial offence has not yet been completed.

In Albania, money laundering is also linked to drug trafficking, trafficking in human beings, corruption, tax evasion and transnational organized crime. In recent years, increased legislative and institutional efforts have been undertaken to approximate domestic legislation with European Union directives. Nevertheless, tracing the financial chain behind criminal activities, effectively applying extended confiscation mechanisms, and strengthening inter-institutional cooperation and international coordination remain major challenges.

In this context, this paper aims to analyses the criminal-law dimension of money laundering, its cross-cutting relationship with organized crime, as well as the legal and institutional indicators and preventive mechanisms designed to address it. The paper also examines the level of implementation of these mechanisms in Albania, in light of international instruments and assessments.

Keywords: money laundering, organized crime, financial investigation, risk index, concealment of assets, illicit origin, asset confiscation.

Introduction

The concept of money laundering refers to the act of concealing the illicit origin of funds through a series of financial transactions designed to make them appear as deriving from lawful sources. Expressions such as "to make dirty money look clean" or "to turn crime into business" have been widely used in legal, economic and media discourse to describe the essence of money laundering.

The term "money laundering" was first used in a legal sense in the United States in the 1970s, during the Watergate investigations, and was subsequently incorporated into international legislation. Later, the Basel Committee on Banking Supervision, composed of representatives of central banks and supervisory authorities from several developed economies, recommended the implementation of a series of measures and rules

aimed at organising the fight against money laundering.[1]

In 1989, the G7 established the Financial Action Task Force, commonly known as FATF, which has since become the leading international standard-setting body in the field of anti-money laundering and counter-terrorist financing.[2] FATF currently operates through a global network that includes its members and regional bodies such as MONEYVAL and the Asia/Pacific Group on Money Laundering, covering almost all jurisdictions worldwide. In 1990, FATF issued its first set of Forty Recommendations,[3] which have been widely accepted and incorporated into the criminal, civil and administrative legislation of many States. Their implementation and monitoring involve a broad range of institutions, including law enforcement authorities, banks, prosecution offices, customs authorities and financial intelligence units.

The first international instrument that defined the core elements of money laundering was the 1988 Vienna Convention.[4] Subsequently, in 2000, the United Nations adopted, through Resolution 55/25, the United Nations Convention against Transnational Organized Crime, known as the Palermo Convention, which includes provisions on combating money laundering in Articles 6 and 7, while Articles 12, 13 and 14 regulate the confiscation of proceeds of crime. Furthermore, the 2003 United Nations Convention against Corruption contains anti-money laundering measures in Articles 14, 23 and 24, while Article 31 and Articles 51 to 59, under Chapter V, regulate the freezing, seizure, confiscation and recovery of proceeds of crime.

The Council of Europe Convention on Laundering, Search, Seizure and Confiscation of the Proceeds from Crime and on the Financing of Terrorism, adopted in Warsaw on 16 May 2005[5], required Member States of the Council of Europe and other signatory States to adopt the necessary legislative and other measures to establish a comprehensive regulatory and supervisory regime for the prevention of money laundering, taking into account applicable international standards and, in particular, the FATF Recommendations.

According to United Nations estimates[6], the amount of money laundered globally each year is estimated to account for between 2 and 5 per cent of global gross domestic product, equivalent to approximately USD 800 billion to USD 2 trillion. In 2024, this estimate would correspond to approximately USD 2.22 trillion to USD 5.54 trillion.[7] In 2023, around USD 3.1 trillion in illicit funds circulated through the global financial system, financing crimes such as trafficking in human beings, estimated at USD 346.7 billion, drug trafficking, estimated at USD 782.9 billion, and terrorist financing, estimated at USD 11.5 billion.[8] During the same year, fraud and banking fraud schemes generated projected global losses of approximately USD 485.6 billion.

Nevertheless, despite these figures, due to the concealed nature of money laundering and the sophisticated methods used to carry it out, it remains difficult to determine with precision the total amount of money that passes through the laundering cycle. These estimates, however, demonstrate the extensive scale of this criminal activity, which not only undermines national economies, but also seriously affects public security. These laundered funds are often used to finance further criminal offences, including drug trafficking, corruption, trafficking in human beings and other organised criminal activities. There is a cross-cutting relationship between organised crime and money laundering, as organised criminal groups use money laundering not only to preserve assets acquired unlawfully, but also to exert political and economic influence in the States in which they operate. This makes money laundering not merely an economic problem, but also a direct threat to the rule of law and institutional stability.

In Albania, the domestic legal framework is undergoing a continuous and intensive process of alignment with international standards. However, its practical implementation remains challenging due to limited resources, institutional capacities and insufficient cooperation among law enforcement agencies. Successful cases pursued by SPAK[9], including a number of criminal proceedings concerning offences related to the

[1] BCBS, Basel Committee on Banking Supervision, http://www.bis.org/bcbs

[2] G7 is an informal political and economic grouping composed of seven advanced economies: the United States of America, Canada, Japan, Germany, France, Italy and the United Kingdom.

[3] FATF (Task-Forca e Veprimit Financiar) , International Standards on Combating Money Laundering and the Financing of Terrorism&Proliferation(pwrditwsuar qershor 2025) https://www.fatf gafi.org/en/publications/Fatfrecommendations/Fatf-recommendations.html The well-known 40 Recommendations are divided into seven distinct areas: AML/CFT policies and coordination; money laundering and confiscation; terrorist financing and proliferation financing; preventive measures; transparency and beneficial ownership of legal persons and legal arrangements; powers and responsibilities of competent authorities and other institutional measures; and international cooperation.These Recommendations were first developed in 1990 as an initiative to combat the misuse of financial systems by persons laundering proceeds derived from drug trafficking. They were subsequently revised in 1996, 2003 and, most recently, in 2012, in order to reflect changes in criminal practices and international challenges, including terrorism and emerging financial risks.

[4] Article 3.1 of this Convention defines money laundering as: "the conversion or transfer of property, knowing that such property is derived from any criminal offence, for the purpose of concealing or disguising the illicit origin of the property, or of assisting any person involved in such an offence to evade the legal consequences of his or her actions."

[5] Ratifed by the law no. 9646, dt.27.11.2006

[6] UNODOC, https://www.unodc.org/unodc/en/money-laundering/index.html?ref=menuside

[7] Payment Industry Intelligence Payments, https://www.paymentscardsandmobile.com/the-global-impact-of-money-laundering-in-2024,

[8] Global Financial Crime Report 2024: Insights at the Intersection of Financial Crime Data & Real Survivor Stories https://www.nasdaq.com/global-financial-crime-report?com

[9] According to the 2023 and 2024 annual reports, "During the period 2021–2024, criminal proceedings concerning offences related to the 'laundering of the proceeds of a criminal offence or criminal activity' followed an upward trend, as presented below. Statistical data show that, in 2024, the number of proceedings registered by the Special Prosecution Office

laundering of proceeds of crime under Article 287 of the Criminal Code, as well as significant seizures carried out in recent years[10], indicate a notable improvement in the institutional response. According to FATF[11] and MONEYVAL[12] assessments, Albania has made important progress in meeting anti-money laundering criteria, which led to its removal from the grey list in October 2023. [13]

As money laundering is increasingly identified as a criminal offence closely linked to corruption and organised crime, the key mechanisms for limiting the financial power of criminal groups remain the prevention of corrupt practices, close coordination and cooperation among law enforcement institutions, and a higher level of seizure and criminal confiscation of illicit assets.

This paper is based on official statistics, reports of domestic and international institutions, as well as key legal and policy instruments, including the Palermo Convention, the Warsaw Convention, the FATF Recommendations, MONEYVAL assessments, European Commission reports, European Union directives and the Global Money Laundering Index.

1. The Money Laundering Risk Index across Different Countries and in Albania

Based on the global impact of money laundering in 2024, [14] as referred to above, an analysis of countries such as the United States, the United Kingdom, Germany, Russia and China, as well as regions such as the Nordic region and Sub-Saharan Africa, shows that significant levels of money laundering have been reported, including the following:

In the United States, approximately USD 300 billion was laundered annually, specifically in 2022. In the United Kingdom and Germany, the estimated amount reached around USD 100 billion, with a low level of awareness observed in high-risk sectors such as real estate and the art trade. In Russia, approximately USD 1 trillion in illicit funds was transferred abroad in 2022, while the "Russian Laundromat" project revealed that 19 banks had laundered USD 20.8 billion during the period 2011–2014. In China, the estimated amount reached USD 154 billion. Sub-Saharan Africa does not report a precise figure regarding money laundering; however, the region is assessed as presenting a very high level of risk, due to corruption, lack of transparency and weaknesses in the rule of law. By contrast, the Nordic region remains the only region assessed as having a lower level of risk, including Finland, Sweden, Iceland and Norway, which have implemented strong regulatory frameworks and innovative solutions.

In June 2024, the Financial Crimes Enforcement Network,[15‹16] an office of the United States Department of the Treasury, proposed new rules requiring financial institutions to conduct risk assessments and strengthen their anti-money laundering programmes.

In comparison, the Italian model has developed an advanced system for pursuing money laundering, in which the role of anti-mafia institutions and the enforcement of anti-money laundering legislation are considered among the most effective in Europe. Similarly, the German model combines advanced technology with institutional cooperation in order to trace, seize and confiscate illicit assets efficiently. Both approaches rely on strong legal instruments for preventive or provisional confiscation, thereby depriving the users and beneficiaries of criminal assets of the opportunity to conceal, transfer or dispose of such assets during the investigation. A further good practice is the use of evidence obtained from financial administration and tax authorities, which may provide a stronger evidentiary basis for criminal prosecution.

Italy was among the first countries to adopt confiscation measures as a tool to target the financial power of organised crime and to confiscate profits derived from criminal activities.[17] These measures shift the burden of proof to the owner of the assets, who is required

in the framework of the fight against the laundering of the proceeds of a criminal offence or criminal activity increased by approximately 34% compared with 2023. Compared with 2021, the number of such proceedings has tripled." www.Spak.al

[10] The value of assets seized and confiscated by SPAK for 2024 is estimated at approximately EUR 65.5 million. This includes the value of assets seized and confiscated under the Anti-Mafia Law, the Criminal Code and the Normative Act related to OFL. Of the total amount, approximately EUR 36.8 million represents the value of confiscated assets, while approximately EUR 28.7 million represents the value of seized assets. SPAK notes that the value of seized assets increased significantly in 2024, by approximately 47%, rising from ALL 1.9 billion in 2023 to approximately ALL 2.8 billion in 2024, according to the SPAK Annual Report 2024. https://spak.gov.al/wp-content/uploads/2025/04/Raporti-vjetor-SPAK-2024.pdf, faqe 20.

[11] FATF publication 23 October 2023 https://www.fatf-gafi.org/en/home.html https://www.fatf-gafi.org/content/fatf-gafi/en/countries/detail/Albania.html,High-risk-and-other monitored-jurisdictions/Increased-monitoring-october-2023.html

[12] MONEYVAL's 4th Follow-up Report, published in May 2023 https://rm.coe.int/moneyval-2023-2-fur-albania/1680abad5a This report highlights significant improvements in transparency, beneficial ownership and international legal assistance. Albania has achieved full compliance with 6 of the 40 FATF Recommendations and is rated as largely compliant with 31 others, while only 2 Recommendations remain rated as partially compliant. This demonstrates that the country is in a stable phase of improvement and enhanced supervision in relation to international AML/CFT standards.

[13] In February 2023, FATF stated that Albania had substantially completed its action plan and commended the country's efforts to address its strategic deficiencies. Following the withdrawal of the draft law by Albania, FATF conducted an on-site visit in August 2023. Albania was subsequently removed from the grey list in October 2023.

[14] The global impact of money laundering 2024 https://www.peachwire.com/

[15]FinCEN is a bureau of the U.S. Department of the Treasury. Its mission is to safeguard the financial system from illicit activity, combat money laundering and terrorist financing, and promote national security through the strategic use of financial authorities, as well as the collection, analysis and dissemination of financial intelligence.

[16]Press realease https://www.fincen.gov/news/news-releases/fincen-issues-proposed-rule-strengthen-and-modernize-financial-institutions

[17] Parliamentary Assembly of the Council of Europe https://assembly.coe.int/nw/xml/XRef/Xref-XML2HTML-

to justify their lawful origin. They do not require a prior criminal conviction, and all assets whose lawful origin cannot be demonstrated may be seized and subsequently confiscated. Italian legislation distinguishes between asset-related "non-conviction-based" measures, also known as preventive measures, and "judicial confiscation" orders, which are based on a criminal conviction and are imposed within criminal proceedings.

In 1982, the Rognoni–La Torre Law[18] introduced the confiscation of assets belonging to suspected mafia members, whereby it was sufficient for there to be a suspicion that a person belonged to a mafia-type organisation. Under this law, two conditions had to be met for seizure to be ordered:

- the assets had to be, directly or indirectly, at the disposal of the suspect; and
- there had to be a disproportion between the assets and the suspect's declared income, or sufficient evidence that the assets constituted proceeds of crime or income derived from their use. The suspect was required to provide sufficient evidence to justify that his or her assets were not the proceeds of criminal activity.

In the analysis of the confiscation of criminal assets, it has been concluded that States such as Ireland, Italy, the Netherlands and the United Kingdom, which have adopted legislation aimed at facilitating the confiscation of criminal assets by lowering or, in certain circumstances, even reversing the burden of proof, or by establishing rebuttable factual presumptions, have been significantly more successful in freezing and confiscating criminal assets than those States which have maintained the requirement that the State prove the link between the assets of the person concerned and his or her criminal activity, or, as is still the case in some jurisdictions, even the link between a specific offence and a specific asset targeted for confiscation.

A distinguishing feature from a criminal-law perspective is that this offence is considered independent from the predicate offence. This means that, even where the predicate offence is not fully proven, or where its prosecution is impossible for procedural or jurisdictional reasons, criminal prosecution for money laundering may still stand as an autonomous offence.

If the technical compliance status of Albania's legal framework is compared with that of Italy, based on the findings of a European Commission report on the Italian anti-money laundering system[19], no significant difference appears to exist in terms of the level of technical compliance of the legal framework, which is almost comparable to Albania's current status.

Currently, the technical compliance indicators of the legal framework relating to the 40 FATF Recommendations, as referred to earlier in this paper, show that, according to MONEYVAL's assessment, Albania is rated as largely compliant with 31 Recommendations, compliant with 6 Recommendations, partially compliant with 2 Recommendations, and non-compliant with none. The two Recommendations rated as "partially compliant" correspond respectively to Recommendation 7 and Recommendation 15, namely: "Targeted financial sanctions related to the financing of proliferation of weapons of mass destruction" and "New technologies – virtual asset service providers".

In this regard, the adoption of the law "On some additions and amendments to Law No. 72/2019 'On International Restrictive Measures in the Republic of Albania",[20] approved in the plenary sitting of the Assembly on 14 December 2023, as well as the "Action against Economic Crime in Albania" project, a joint programme of the Council of Europe and the European Union, are expected to contribute to improving the compliance rating of these Recommendations in line with international standards.

Likewise, at the comparative level of aggregated indicator assessment, the results of the Basel Institute, [21] presented in its 2023 report and covering 152 countries, including Albania, show that Albania was ranked globally with a score of 4.75, placing 93rd. Compared with previous years, Albania has made notable progress in its positioning. In 2022, Albania was ranked with a score of 4.92, placing 74th, while in 2021 it had a score of 5.72. Meanwhile, in 2024[22], Albania made further visible progress, reaching a score of 4.35, which places it within the same risk indicator range as Austria and Armenia, and ranking 128th. This result places Albania ahead of countries such as Italy, with a score of 4.80 and ranking 102nd, Germany, with a score of 4.63 and ranking 114th, and the United States, with a score of 4.81 and ranking 101st.

EN.asp?fileid=24507&utm:~:text=Fighting%20organised%20crime%20by%20facilitating%20the%20confiscation%20of%20illegal%20assets

[18] Press article https://www.nuovogiornalenazionale.com/

[19] European Commission, The Italian System for Anti-Money Laundering and Countering the Financing of Terrorism https://commission.europa.eu/document/doënload/94d90bd1-6fa2-4d7e-b960-cf047785b4bd_en?filename=Additional+documentation+Italy_The+Italian+AML-CFT+institutional+system.pdf

[20] With regard to FATF Recommendation 7, this evaluation round found that the Albanian legal framework was rated non-compliant (NC), as this Recommendation had not yet been addressed within the domestic regulatory system. Following this assessment, Recommendation 7 was addressed through the provisions of Law No. 72/2019 "On International Restrictive Measures in the Republic of Albania" and was subsequently reviewed at the 61st MONEYVAL Plenary, held in April 2021. As a result, the rating for this Recommendation was upgraded from NC — non-compliant to PC — partially compliant.www.parlament.al

[21] The results of the Basel Institute on Governance are derived from the aggregated processing of 18 indicators related to the legal and regulatory framework on AML/CFT, corruption and financial standards, using public sources such as FATF, which has primary weight, the U.S. Department of State report on money laundering, Transparency International, the World Bank and others. The objective of the Institute is to provide a country ranking based on AML/CFT risk, rather than to measure the actual level of "money laundering", since reliable data are not available to allow such an assessment. The current ranking scale ranges from 0, indicating low risk, to 10, indicating high risk, and is divided into three risk levels: 0–3.3 as low risk, 3.3–6.6 as medium risk, and 6.6–10 as high risk.

[22]Index Global Raport http://www.baselgovernance.org/

2. The Criminological Manifestation of Money Laundering in Albania, Methods and Legal Instruments

In Albania, over the years, several significant criminological and legal factors, with specific tendencies, have been identified as having contributed to the emergence, expansion and consolidation of this form of criminality. Among the main factors that have influenced the manifestation and evolution of money laundering are the following:

- the accelerated privatisation process carried out during the transition from the former economic system, in the absence of an adequate legal framework. This created favourable conditions for part of the former State-owned economy to be absorbed by criminal circles, as a result of insufficient control and the State's limited awareness of the phenomenon at the time, thereby creating favourable opportunities for money laundering;
- the prolonged existence of an informal economic system, which facilitated the laundering of criminal proceeds;
- unfair competition and the illegal economy, which created a favourable environment for the unlawful circulation of monetary assets, including the purchase of land, buildings and former State-owned factories in cash;
- the unrestricted presence of various forms of "foreign investment", including investments linked to international organised crime structures;
- the absence of specific legislation aimed at controlling and preventing money laundering;
- the lack of effective supervision by the State Bank over capital movements and financial transactions, as well as over related financial irregularities, together with insufficient control by the Central Bank over second-tier banks;
- deficiencies in the sphere of currency circulation;
- the allowance of financial transactions under conditions of anonymity or fictitious identity.

From a chronological perspective, since the adoption of the Albanian Criminal Code in 1995[23], the criminal provision concerning the alienation, transfer, concealment or suppression of the nature, source or ownership of assets derived from criminal offences was punishable by imprisonment from three to ten years. Over the years, [24] the amendments and legal qualifications of this criminal offence, relating to assets derived from criminal activity, as well as the specific provision on money laundering, have maintained the same fundamental objective: the introduction into lawful circulation of funds or assets originating from criminal activity.

Article 287 of the Criminal Code regulates this conduct by defining money laundering as the "laundering of the proceeds of a criminal offence or criminal activity". This offence may be committed through various forms, including:

a) the exchange or transfer of property, for the purpose of concealing or disguising its illicit origin, while knowing that such property constitutes proceeds of a criminal offence or criminal activity;

b) the concealment or disguise of the true nature, source, location, disposition, movement, ownership or rights relating to property, while knowing that such property constitutes proceeds of a criminal offence or criminal activity;

c) the acquisition of ownership, possession or use of property, while knowing, at the time of receiving it, that such property constitutes proceeds of a criminal offence or criminal activity;

d) the performance of financial operations or structured transactions aimed at avoiding reporting obligations under the legislation on the prevention of money laundering;

e) the investment, in economic or financial activities, of money or assets, while knowing that they constitute proceeds of a criminal offence or criminal activity;

f) counselling, assisting, inciting or publicly calling for the commission of any of the acts listed above.

The commission of any of the above-mentioned acts is punishable by imprisonment from five to ten years. Where the offence is committed in the exercise of a professional activity, in cooperation with others, or more than once, it is punishable by imprisonment from seven to fifteen years. The same offence, where it has caused serious consequences, is punishable by imprisonment for not less than fifteen years.

Article 287, including its subsequent amendments, presents several important characteristics:

- the offence may be autonomous from the predicate offence, allowing criminal prosecution even in the absence of a prior conviction for the offence that generated the assets;
- the concept of "money" is broadened to include any type of asset, whether financial, physical or banking-related;
- the provision covers both active and passive conduct, including not only the concealment, but also the possession or use of illicit funds.

The main domestic legal framework serving the prevention of money laundering and terrorist financing is as follows:

- **Law No. 9917/2008 "On the Prevention of Money Laundering and Terrorist Financing", as amended**, which aims to prevent money laundering and the laundering of proceeds derived from criminal offences, as well as to prevent terrorist financing; [25]

[23] Criminal Code of the Republic of Albania https://www.qbz.gov.al/preview/a2b117e6-69b2-4355-aa49-78967c31bf4d

[24] In the following years, the criminal offence of money laundering was amended several times, namely in 2001, 2003, 2004, 2007, 2012 and 2013, mainly as a result of the approximation of domestic legislation with ratified international conventions, as well as in response to internal legal and institutional needs.

[25] Law No. 9917, dated 19 May 2008, "On the Prevention of Money Laundering and Terrorist Financing", as amended by Law No. 10 391, dated 3 March 2011; Law No. 66/2012,

- **Law No. 157/2013 "On Measures against Terrorist Financing", as amended**, which provides the legal mechanisms for preventing and combating the activities of terrorists, persons who support or finance terrorism, as well as persons in respect of whom there are reasonable grounds to suspect that they have committed, are committing, or intend to commit such activities. The law provides for measures such as the freezing and seizure of funds and assets, in implementation of the relevant resolutions of the United Nations Security Council, acts of other international organisations, and international agreements to which the Republic of Albania is part. [26]

This legal framework has been approximated with European Union legislation on the prevention of the use of the financial system for the purposes of money laundering or terrorist financing, namely the Fourth, Fifth and Sixth EU Anti-Money Laundering Directives. These directives require clear rules on the screening and monitoring of politically exposed persons, the reporting of suspicious transactions, and the use of registers on the beneficial ownership of legal entities. [27،28]

In May 2024, the European Union adopted the new Anti-Money Laundering package, which provides for the establishment of a common authority for anti-money laundering supervision and strengthens transparency regarding beneficial ownership across the European Union. [29]

In 2024, Albania established the **Financial Intelligence Agency (FIU)**, which replaced the General Directorate for the Prevention of Money Laundering. The FIU operates as the central authority responsible for the collection, analysis and dissemination of financial information related to potential money laundering and terrorist financing activities. It cooperates closely with law enforcement institutions and supervisory authorities in order to strengthen the preventive system and ensure compliance with legal requirements.

For methodological purposes, this paper will refer to some of the forms and methods addressed by experts in the field, as well as the most widespread techniques currently used worldwide for the legalisation of financial assets or other property obtained through unlawful means, commonly referred to as the "laundering of dirty money".[30]

2.1 The Stages of legalizing Money Laundering

Money laundering involving criminal proceeds develops through several stages, and in each of them the objectives, forms, tools, and methods to be used are determined. The division into stages is conventional; indeed, each stage aims to achieve the main objective, such as:

- Introducing money and capital of criminal origin into the legal monetary circulation, mainly through cash transactions[31];
- Distancing criminal proceeds from their original sources;
- Integrating and investing them into the legal economy.

"During the first stage", the introduction of "dirty money" (cash) into the legal economic circulation takes place. At this stage, preliminary actions are often used to facilitate later operations, such as exchanging money into securities, valuable goods, or foreign currency.

Some of the methods include:

- Using businesses with high cash turnover to mix illegal money with legitimate revenue;
- Creating fictitious enterprises or entities to declare dirty money as profits that need to be laundered;
- Blackmailing or bribing individuals responsible for customer identification, such as bank employees or others involved in verification procedures;
- Organizing purchases with cash of goods that can quickly be converted into assets;
- Making purchases below the legal threshold that requires verification of the origin of funds;
- Depositing relatively small sums of money and carrying out frequent bank account transactions;
- Organized exchange of money into valuables or foreign currency without using bank accounts;
- Illegal transportation of money abroad;
- Creating legal lending businesses with attractive high-interest rates, such as pyramid schemes;

dated 7 June 2012; Law No. 44/2017, dated 6 April 2017; Law No. 33/2019, dated 17 June 2019; Law No. 120/2021, dated 2 December 2021; and Law No. 62/2023, dated 21 July 2023.

[26] Law No. 157/2013 "On Measures against Terrorist Financing", as amended by Law No. 43/2017, dated 6 April 2017; Law No. 32/2019, dated 17 June 2019; and Law No. 63/2023, dated 21 July 2023.

[27] Directive 4 (EU) 2015/849 of the European Parliament and of the Council of 20 May 2015 on the prevention of the use of the financial system for the purposes of money laundering or terrorist financing , https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32015L0849 e ndryshuar me Directive 5(EU) 843/2018 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018L0843

[28] Directive (EU) 2018/1673 of the European Parliament and of the Council of 23 October 2018 on combating money laundering by criminal law, https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32018L1673

[29] On 30 May 2024, the Council of the European Union announced the adoption of the Anti-Money Laundering package, which sets out the key details concerning the establishment of AMLA and the measures aimed at strengthening transparency of beneficial ownership.https://www.consilium.europa.eu/en/press/press-releases/2024/05/30/anti-money-laundering-council-adopts-package-of-rules

[30] Prof. Dr. Luan Gjoncaj, Legalisation of Assets Acquired through Criminal Means: "Laundering of Dirty Money", conference paper presented during the scientific session, American University of Tirana, 2015.

[31] (3 staging of money laundering: placement, layering, integration).
https://www.unodc.org/unodc/en/moneylaundering/overview.html#:~:text=3%20Stages%20of%20Money%20Laundering

1. Placement: The placing of illegally obtained funds into the financial system, for example, by depositing cash in banks or investing them in property.
2. Layering: The carrying out of a series of complex transactions and distributions of money to conceal its original source. This includes international transfers, the purchase of real estate, or the use of shell companies.
3. Integration: The final incorporation of the money into the formal economy, where it can be used for legitimate investments, spending, or trade, thereby giving it legitimacy.

- Establishing charitable funds or foundations to introduce dirty money into circulation, directed toward governmental and non-governmental organizations;
- Using gifts or membership fees that are exempt from taxation systems.

In **"the second stage"**, criminal organizations use recruited individuals and the enterprises described above to separate criminal proceeds from their original sources. This stage is characterized by the planning and implementation of complex financial and economic operations, which require not only criminal intent but also specialized knowledge and practical skills from those who organize them. These include:

- Organizing a series of complex financial operations aimed at erasing traces of criminal activity and concealing the identities of the individuals involved, creating anonymity for both assets and people;
- "Shell" or fictitious companies presenting fake accounts of their "activities," through which dirty money is transformed into apparently legitimate funds ready to enter circulation;
- Introducing dirty money into the legal economy through illegal enterprises with vertical and horizontal links, presenting it as business profits or through schemes that artificially increase capital;
- International financial operations through states with lenient tax regimes or offshore zones;
- International financial operations in countries with weak or underdeveloped financial control systems.

The schemes used in these operations are not fixed; they evolve depending on economic conditions and the effectiveness of oversight mechanisms. This is also what makes their detection difficult. In investigations aimed at uncovering illegal activities of unlawful enterprises, accounting control through standard economic analysis methods takes priority. This may lead to accurate conclusions and the identification and documentation of possible criminal money laundering activities by comparing indicators such as income, liquidity, relationships between entrepreneurs, business connections, etc.

"The third stage" represents the finalization stage of the operations**,** where dirty money incorporates into the legal circulation and the conditions to establish the "legal origin" of money derived from crime are established. This stage involves creating a convincing perception of the "clean" origin of dirty money and integrating it into normal legal circulation.

The forms are numerous, but some examples include:

- Financial operations aimed at reducing or avoiding taxes;
- Deals involving undervalued prices and real estate operations. For example, purchasing real estate at a "low price" while compensating the difference between the real value and the purchase price with illegal money, followed by a "revaluation" and resale at market value. As a result, clean legal income is generated and becomes ready for legal circulation;
- Loans and interest payments. In such cases, the money is declared as belonging to a foreign company that either grants a "loan" or provides guarantees for bank credit.

"The fourth stage" pertains to the investment of dirty money into the legal economy constituting thus the concluding stage of the entire money laundering operation. It finalizes the efforts of criminal organizations to reintegrate criminal capital into circulation in a lawful form. This materializes through:

- Direct investments in various sectors of the economy, representing the active integration of laundered money into the legal market through investments;
- Turning institutions or sectors into legal components of clandestine criminal operations;
- Creating the vicious cycle of the criminal legalization scheme of money and unlawfully obtained assets: "Money – Goods – Money," which represents the essence of these criminal operations.[32]

According to the annual report of SPAK for 2024[33], there is a growing trend in the use of cryptocurrencies as a means of purchasing drugs, either directly or through currency exchange offices. This offense poses a high level of danger, as there has been an increase during the years 2022–2024. Furthermore, investigations into corruption-related criminal offenses have revealed forms of money laundering such as the indirect transfer of public funds by public officials to private entities and their subsequent reinvestment into real estate, payment for fictitious works and investments in real estate, falsification of documents for the registration of illegally acquired assets, transfer of assets to new beneficiaries who later alienate them, as well as money laundering through fictitious contracts and investments favoring commercial entities to unlawfully obtain public property and public funds.

3. Recent Data on the Implementation of Legal and Institutional Instruments Related to the Prevention of Money Laundering in Albania

The Head of the Special Prosecution Office, Altin Dumani[34], during his report before the Parliamentary Commission on Legal Affairs in the Assembly of Albania on May 22, 2024, stated that European countries such as Germany, Belgium, Netherlands, Italy, Spain, the Scandinavian countries, and United Kingdom view Albania as an attractive destination for investing the proceeds of criminal offenses derived from trafficking. He further emphasized that there has been an increase in the number of criminal proceedings for money laundering, both in 2023 and according to the trend observed in 2024, leading to increased attention toward these criminal phenomena through continuous cooperation with law enforcement agencies such as Europol, Eurojust, all EU countries, and the region. "*There was*

[32] Prof. Dr. Luan Gjoncaj, Informal Economy, Article in the Journal of Police 2005.

[33] Published in the official website of the Parliament of Albania (2025), as well as in the official website of SPAK, , www.spak.al/raporte

[34] Ibid.

an exponential increase in 2023, and the trend continues in 2024. Investigations up to the end of 2023 show that there is a very large circulation of cash money. The legislation is good, but the problem lies in its implementation. Institutions must enforce it."

The report indicates that the primary method of money laundering in Albania is investment in movable and immovable property, especially apartments, buildings, and service units in Tirana and tourist areas such as Vlora, Durrës, and Lezha. Furthermore, a significant amount of money is suspected of being deposited into bank accounts under the names of commercial companies or relatives of suspects. One of the complex money laundering schemes in Albania involves the use of Albanian banks and businesses as intermediaries for international criminal organizations, such as the Italian mafia.

Although Albania's removal from the grey list of Moneyval is considered an achievement of the Albanian state[35] and aligns with the positive declaration of the International Monetary Fund (IMF)[36], which stated that the country's economy "has emerged as one of the strongest performers in the region" and that "expectations for Albania's economy are expected to remain stable," there still remains an increased risk within the banking system, particularly concerning second-level banks, the concrete role of the Bank of Albania, and the monitoring of transactions and reporting by the Financial Intelligence Agency.

Referring to the reports of the FIU[37] (Financial Intelligence Unit, established under the latest amended law in 2023), the indicators showing the most widespread methods of money laundering include: Investment in real estate; Investment in movable assets; Investment in the development or management of real estate as a business; Investments in trade; Investments in the energy sector; Investments in information technology; Investments in the construction sector.

Albania has intensified its institutional and legal efforts to identify, prevent, and combat money laundering. The National Strategy[38] "On the Prevention of Money Laundering and Terrorist Financing 2024–2030" has been adopted. This document identified shortcomings such as low levels of investigations and criminal prosecutions for money laundering/terrorist financing, weaknesses in information exchange, and legislative gaps, which have been continuously addressed through the approval of legal and sub-legal acts. It also established priorities grouped into six objectives: (1) Improving the regulatory framework and strengthening interinstitutional coordination; (2) Further increasing the effectiveness of the preventive system; (3) Improving the operational efficiency of law enforcement bodies and other agencies in combating money laundering/terrorist financing; (4) Using and exploiting technological innovations while reducing risks; (5) Increasing the effectiveness of the supervisory system; (6) Strengthening international cooperation.

The 2024 report of the European Commission on Albania[39], points out that: "*Albania should continue developing the systematic use of financial investigations in cases involving organized crime, illegal trafficking, terrorism, and money laundering," and should also ensure that any voluntary tax compliance or amnesty legislation complies with the relevant EU acquis and international standards established by Moneyval and the Financial Action Task Force"*.

It appears that SPAK's attention has turned toward this recommendation, materialized through the adoption of bylaws and the issuance of guidelines on financial investigation measures[40]. From an institutional perspective, within the framework of the justice reform, significant work has been carried out in the fight against corruption through the establishment of institutions such as: The Special Prosecution against Corruption and Organized Crime (SPAK), the National Investigation Burau (BKH) and the Court of first instance and of Appeal against Corruption and Organized Crime (GJKKO). For the past four years, these institutions have attached special importance to combating the laundering of criminal proceeding by pursuing an approach that combines criminal investigations with asset investigations.

Regarding the specific regulation provided by the Criminal Code on organized crime, specifically Articles 333 and 334[41], which sanction respectively:

The organization of a structured criminal group and participation in such a group, in the context of their connection with money laundering, it is important that

[35] Statement of the Minister of Infrastructure. Shqipëria del nga lista gri e pastrimit të parave - Ministria e Infrastrukturës dhe Energjisë (infrastruktura.gov.al)

[36] International Monetary Fund, "Albania: Staff Concluding Statement of the 2023 Article IV Mission". https://www.imf.org/en/News/Articles/2023/10/27/mcs102723-albania-staff-concluding-statement-of-the-2023-article-iv-mission#:~:text=Albania%3A%20Staff%20Concluding,October%2027%2C%202023

[37] Article, Panorama Gazette dated 18 July 2024. https://www.panorama.com.al/agjencia-e-inteligjences-financiare-nga-investimi-ne-biznese-tek-pasurite-e-paluajtshme-ja-si-i-pastrojne-parate-zyrtaret-e-korruptuar/?utm_source=chatgpt.com#:~:text=Agjencia%20e%20Inteligjenc%C3%ABs%20Financiare%20(AIF,korrupsionit%20apo%20shp%C3%ABrdorimit%20t%C3%AB%20detyr%C3%ABs.

[38] https://fiu.gov.al/njoftim-per-konsultim-publik-draft-strategjia-kombetare-per-parandalimin-e-pastrimit-te-parave-dhe-financimit-te-terrorizmit-2024 2030/#:~:text=Draft%20%E2%80%9CStrategjia%20Komb%C3%ABtare%20p%C3%ABr%20Parandalimin%20e%20Pastrimit%20t%C3%AB%20Parave%20dhe%20Financimit%20t%C3%AB%20Terrorizmit%202024%2D2030%E2%80%9D%20(kliko%20ketu)

[39] https://enlargement.ec.europa.eu/document/download/a8eec3f9-b2ec-4cb1-8748 9058854dbc68_en?filename=Albania%20Report%202024.pdf

[40] Report of SPAK 2023/ SPAK instruction on financial and property investigation. https://spak.gov.al/wp-content/uploads/2024/11/Udhezim-i-pergjithshem-nr-1093-date-11.11.2024-Masat-administrative-dhe-proceduriale-per-kryerjen-e-hetimit-financiar-dhe-pasuror-ne-strukturen-e-Posacme-Kunder-Korrupsionit-dhe-Krimit-te-Organizuar.pdf

[41] Penal Code, special part. https://spak.gov.al/kodet-2/

participation in a criminal organization also be used to justify the link between criminal activity and assets, in the sense of proving the unlawful origin of income.

4. The Effectiveness of the Implementation of the Anti-Mafia Law No. 10192/2009, as amended

A very important law that assists in the prevention and suppression of organized crime and trafficking is Law No. 10192/2009[42], "On the Prevention and Suppression of Organized Crime and Trafficking through Preventive Measures against Property," which has undergone significant improvements over the years by consolidating the concept of civil confiscation and allowing the seizure and confiscation of assets without the need for a final criminal conviction.

Initially, the new law repealed Law No. 9284/2004 in order to resolve the "legal conflict" regarding its effective implementation in practice concerning "the prohibition of seizure and confiscation of all assets, funds, or other properties acquired or obtained by convicted persons before criminal proceedings were initiated against them...". Meanwhile, Law No. 10192/2009 aimed to establish a clear separation between the civil process of seizure/confiscation of illegal assets (balance of probabilities) and the criminal process (beyond reasonable doubt), emphasizing that the proceedings are directed against the property itself (*in rem*) and not against the person (*in personam*).

This law has undergone continuous legal and practical improvements[43] over the years through a series of important amendments, including:

- **Law No. 24/2014, dated 20.03.2014**, expanded the scope of the law by including corruption-related criminal offenses in addition to organized crime and trafficking, which was also reflected in the title of the law.
- **Law No. 70/2017, dated 27.04.2017**, further expanded the scope of the law to include additional crimes and introduced references to the Criminal Procedure Code instead of the Civil Procedure Code regarding verification, investigation, and adjudication under this law.
- **Law No. 85/2020, dated 02.07.2020**, established that the management of seized assets would be carried out by the Agency for the Administration of Seized and Confiscated Assets. These amendments also provided for the creation of the Interinstitutional Committee on Measures against Organized Crime, which was granted supervisory competencies over asset management and decision-making powers regarding the transfer of real rights, methods of use, and the final destination of seized and confiscated assets. The Agency for the Administration of Seized and Confiscated Assets was placed under the authority of the Minister of Interior, removing this competence from the Ministry of Finance.

The purpose of the law consists of confiscating the assets of individuals whose economic level is unjustifiable because of suspected criminal activity.

The scope of application set out in Article 3[44] extends the effects of the law to assets wholly or partially owned, directly or indirectly, where there exists a reasonable suspicion based on indications relating to a range of criminal offenses connected to financial crime.

In implementing the Anti-Mafia Law, SPAK reports that "*during 2024, 17 asset proceedings were registered." Regarding court requests, there were 5 requests for asset seizure and 6 for asset confiscation. Assets seized under Law No. 10192/2009, as amended, are estimated at ALL 1,239,896,351 while confiscated assets under the same law are estimated at ALL 419,679,398. Regarding confiscation of assets in criminal proceedings, 11 decisions have been issued*".

In the latest report of the European Commission, it is emphasized that: "*There has been some progress in the seizure and confiscation of assets linked to organized crime, which should continue in the future*."

It is important that seized or confiscated assets generate benefits that serve as motivating factors for the development of the activities of independent justice institutions, provide direct benefits to vulnerable groups and victims of human trafficking, and contribute to restoring fair competition in the free market by transforming seized or confiscated assets into contributors to the country's economic growth, based on the principles of "legality" and "equality."

However, despite all achievements so far, the Assembly of Albania, in exercising its supervisory function over the implementation of laws, should undertake a post-legislative review process of this law. This has become necessary[45] following 5 years since its latest amendment and the 5 years of functioning of the institutions established through the Justice Reform, in order to assess how its provisions have been implemented, whether they are effective, and what impact they have had on the principal beneficiaries and their rights.

Of particular interest regarding the extension of the implementation of this law are elements related to:

- The extension of the application of this law to cases unrelated to criminal proceedings where there exists reasonable suspicion based on indications for criminal offenses such as "Production and Sale of Narcotics," "Trafficking of Narcotics," and "Organization and Leadership of Criminal Organizations," provided respectively under Articles 283, 283/a, and 284/a of the Criminal Code;
- The level of implementation of this law in cases unrelated to criminal proceedings involving indications of unlawful material gain from the criminal offenses of "Active Corruption of Persons Exercising Public Functions" and "Active Corruption of High

[42] Law No. 10192/2009, "On the Prevention and Combating of Organized Crime, Trafficking, Corruption and Other Crimes through Preventive Measures against Property", as amended, was adopted on 3 December 2009, and came about as a need to improve the legal framework regarding the procedures for the seizure and confiscation of illegal assets generated by organized crime, to be an effective tool in combating crime through preventive measures against property.

[43] Amended during the years.

[44] Article 3, amended by law no. 24/2014, dated 20.03.2014 and amended by law no. 70/2017, dated 27.04.2017.

[45] Post Legislative Scrutiny of laws adopted by the Assembly regarding their implementation and effectiveness, approved with amendments to the Rules of Procedure of the Assembly by Decision No. 6/2025 of the Assembly of Albania.

State Officials or Local Elected Officials," under Articles 244 and 245 of the Criminal Code;

- Whether investigations have been extended to cases unrelated to criminal proceedings, and if civil proceedings were not initiated, why this occurred and what failed in practice;
- How many criminal proceedings or convictions for the offenses of "Active Corruption of Persons Exercising Public Functions" and "Active Corruption of High State Officials or Local Elected Officials" have been accompanied by seizure and confiscation measures where there were indications of unlawful material benefit, including confiscations following final convictions;
- The assessment of indications for initiating judicial proceedings for preventive measures. What percentage of these indications originated from foreign authorities, particularly regarding criminal offenses under Articles 283, 283/a, and 284/a?

Recently, the Albanian Parliament has approved Law No. 44/2025[46] "On the Asset Recovery Office," which is responsible for the process of tracing and identifying proceeds, assets, or other material benefits arising from criminal offenses or criminal activity, or connected thereto, which may be subject to seizure or confiscation by competent authorities. The absence of a specific law until now has made the process of identifying and tracing criminal assets more complicated and slower, often rendering procedures more complex and difficult to implement in practice.

With the adoption of this law, Albania continues fulfilling its obligations within the framework of legislative approximation. In this case, the law has been aligned with several EU Directives, including the most recent, Directive 2024/1260[47] of 24 April 2024 "On Asset Recovery and Confiscation," which constitutes an important EU legal instrument. By consolidating into a single act rules previously scattered across various EU instruments, it aims to harmonize applicable legislation among EU member states regarding issues related to the seizure/freezing and confiscation of assets in criminal proceedings, as well as their administration and recovery, including measures for restriction/seizure and criminal, and more recently civil, confiscation of unlawfully acquired assets.

Conclusions

- There is a close functional connection between money laundering and organized crime, as money laundering is the primary mechanism used to conceal the underlying criminal activities. It also plays a crucial role in the survival of criminal structures and their expansion through infiltration into the economy and state institutions, making the phenomenon of legitimizing organized crime through lawful investments in formal sectors such as construction, real estate, casinos, etc., highly dangerous and threatening.
- Compared to international standards, Albanian legislation is undergoing a continuous process of approximation and demonstrates positive indicators in adopting preventive measures against money laundering. However, the main challenge lies more in the practical implementation of the law rather than in its formal legal framework.
- Despite all indicators of technical compliance of the legal framework and Albania's ranking at the global level, Albania remains at a medium risk for money laundering and terrorist financing.

Some of the main challenges are:

- Increasing independent and in-depth financial investigations separate from investigations of the underlying criminal offense;
- Strengthening and increasing technical and human capacities within the prosecution, police, and other agencies involved in combating money laundering and terrorist financing (ML/TF);
- Increasing the number of effective confiscations of assets derived from money laundering;
- Further consolidating risk-based supervision and increasing the number and diversity of suspicious activity reports;
- Strengthening interinstitutional coordination and consolidating international cooperation, especially regarding the exchange of banking and investigative data;
- Further improving the legal and regulatory framework related to money laundering;
- Ensuring the effective implementation of the legislation in force concerning the prevention of money laundering and terrorist financing, as well as legislation on the seizure and confiscation of illegal assets and assets derived from criminal proceeds.

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STATION–TYPE PENITENTIARIES IN THE REPUBLIC OF AZERBAIJAN: HISTORY, STATUS AND FUTURE PROSPECTS

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AZƏRBAYCAN RESPUBLİKASINDA MƏNTƏQƏ TİPLİ CƏZAÇƏKMƏ MÜƏSSİSƏLƏRİ: TARİXİ, VƏZİYYƏTİ VƏ GƏLƏCƏK PERSPEKTİVLƏRİ

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Azərbaycan Respublikası, Bakı şəhəri

Abstract
The history and development of station-type penitentiaries in the Republic of Azerbaijan, the experience of serving sentences in these institutions are reviewed, and proposals are made to improve their activities and solve existing difficulties.

Xülasə
Azərbaycan Respublikasında məntəqə tipli cəzaçəkmə müəssisələrinin yaranma tarixi, inkişafı, həmin müəssisələrdə cəzanın icrası təcrübəsi nəzərdən keçirilir, onların fəaliyyətinin təkmilləşdirilməsinə, mövcud çətinliklərin həllinə yönəlmiş təkliflər verilir.

Keywords: Republic of Azerbaijan, Criminal Code, Correctional and Labor Code, Code of Execution of Sentences, imprisonment, station-type penal institutions.
Açar sözlər: Azərbaycan Respublikası, Cinayət Məcəlləsi, İslah-Əmək Məcəlləsi, Cəzaların İcrası Məcəlləsi, azadlıqdan məhrum etmə cəzası, məntəqə tipli çəzaçəkmə müəssisələri.

Azərbaycan Respublikasının Cinayət Məcəlləsinin (bundan sonra AR CM) 56-cı maddəsinə uyğun olaraq azadlıqdan məhrum etmə növündə cəzalara məhkum edilmiş şəxslər cəzalarını müxtəlif növlü cəzaçəkmə müəssisələrində çəkirlər. Məhkəmə, cəzaçəkmə müəssisəsinin növünü cinayət qanununa istinadən, yəni məhkum edilən şəxsin yaşını, cinsini, törədilmiş cinayətin ağırlıq dərəcəsini, təqsirin növünü, keçmiş məhkumluğunu, təyin edilmiş cəzanın müddətini nəzərə almaqla müəyyənləşdirir [1, Səh. 80]. AR CM-in sözügedən maddəsində azadlıqdan məhrum etmə cəzasının çəkilməsi yeri kimi məntəqə tipli cəzaçəkmə müəssisəsi də müəyyən edilmişdir. Ehtiyatsızlıqdan törədilmiş cinayətlərə görə beş ildən artıq olmayan müddətə azadlıqdan məhrum etməyə məhkum olunmuş şəxslərə cəzanın çəkilməsi yeri məntəqə tipli cəzaçəkmə müəssisəsi təyin edilir. Eyni zamanda, Azərbaycan Respublikasının Cəzaların İcrası Məcəlləsinin (bundan sonra AR CİM) 70-ci maddəsinin ilkin redaksiyasında ümumi və ciddi rejimli cəzaçəkmə müəssisələrində müsbət xarakterizə olunan, cəza müddətinin ən azı üçdə birini, xüsusilə ağır cinayətlər törətməyə görə məhkum olunan və ya müəyyən müddətə azadlıqdan məhrum etmə növündə cəzadan şərti olaraq vaxtından əvvəl azad edilmiş, lakin cəzanın çəkilməmiş hissəsi dövründə yeni cinayət törətmiş məhkumların isə, cəza müddətinin ən azı üçdə ikisini çəkdikdən sonra məntəqə tipli cəzaçəkmə müəssisəsinə keçirilməsi imkanı nəzərdə tutulmuşdu. Sözügedən maddədə məntəqə tipli cəzaçəkmə müəssisəsinə keçirilməsi qadağan edilmiş məhkumların siyahısı da verilmişdi. Belə ki, cinayətlərin xüsusi təhlükəli residivinə görə məhkum olunmuş, ömürlük azadlıqdan məhrum etmə növündə cəzası müəyyən müddətə azadlıqdan məhrum etmə növündə cəza ilə əvəz edilmiş, habelə tibbi xarakterli məcburi tədbirlər keçməli olan şəxslər məntəqə tipli cəzaçəkmə müəssisəsinə keçirilə bilməzdilər.

Azərbaycan Respublikasının 27 dekabr 2001-ci il tarixli Qanunu ilə AR CİM-in 70-ci maddəsinə edilmiş dəyişikliyə əsasən ağır cinayətlərə görə məhkum edilmiş şəxslərin məntəqə tipli cəzaçəkmə müəssisəsinə keçirilməsi şərti dəyişdirilmiş, çəkilməsi tələb olunan müddət artırılaraq, təyin olunmuş cəzanın ən azı üçdə ikisi müəyyən edilmişdir. Ölkənin 31 may 2011-ci il tarixli Qanunu ilə edilmiş digər dəyişikliyə uyğun olaraq isə, məntəqə tipli çəzaçəkmə müəssisəsinə kecirilməyən şəxslərin dairəsi genişləndirilərək, müvafiq siyahıya ciddi rejimli çəzaçəkmə müəssisələrində cəza çəkən, habelə AR CİM-in 70-ci maddəsinə uyğun olaraq ciddi rejimli cəzaçəkmə müəssisələrindən ümumi rejimli cəzaçəkmə müəssisələrinə keçirilmiş məhkumlar da əlavə edilmişdir. Sonuncu dəyişiklik məntəqə tipli çəzaçəkmə müəssisəsinə keçirilən məhkumların sayının azalmasına səbəb olmuşdur. AR CİM-in 70-ci maddəsinin qüvvədə olan redaksiyasına uyğun olaraq ümumi rejimli cəzaçəkmə müəssisələrində müsbət xarakterizə edilən, ilk dəfə böyük ictimai təhlükə törətməyən, az ağır cinayətlərə görə məhkum edilmiş şəxslər, onlara təyin edilmiş cəza müddətinin üçdə birini, ağır cinayətlərə görə məhkum edilmişlər isə, üçdə ikisini çəkdikdən sonra məhkəmənin qərarı ilə məntəqə tipli cəzaçəkmə müəssisəsinə keçirilə bilərlər. Beləliklə, qüvvədə olan qanunvericiliyə əsasən Azərbaycan Respublikasında azadlıqdan məhrum etmə cəzasının çəkilməsi yeri kimi müəyyən edilmiş məntəqə tipli cəzaçəkmə müəssisəsinin iki növü mövcuddur. 2025-ci ilin sonuna Azərbaycan Respublikasında, biri Naxçıvan Muxtar

Respublikasının ərazisində olmaqla, on beş məntəqə tipli cəzaçəkmə müəssisəsi fəaliyyət göstərirdi.

Məntəqə tipli cəzaçəkmə müəssisəsi digər növlü cəzaçəkmə müəssisələrindən cəzanın icrası şərtləri və cəzaçəkmə müəssisələrinin Daxili İntizam Qaydaları (bundan sonra CÇM DİQ) ilə müəyyən olunmuş quruluşu ilə fərqlənir. Belə ki, sözügedən müəssisələr cəzaların icrası qanunvericiliyinə uyğun olaraq silahlı mühafizə olunmur, yüksək hasarlarla əhatə edilmir, kamera tipli otaqlara (binalara) malik deyillər. Məhkumlar məntəqə tipli cəzaçəkmə müəssisələrinin daxilində, habelə müəyyən məhdudiyyətlərlə onların yerləşdiyi ərazidə sərbəst hərəkət edə bilərlər, cəzanın icrası şərtləri digər növlü cəzaçəkmə müəssisələri ilə müqayisədə xeyli humanistdir. Buna görə də bir sıra dövlətlərdə onları açıq cəzaçəkmə müəssisəsi də adlandırırlar. Hazırda məntəqə tipli cəzaçəkmə müəssisələri əvvəllər sabiq Sovet Sosialist Respublikaları İttifaqının (bundan sonra SSRİ) tərkibində olmuş respublikaların, habelə onlara oxşar açıq müəssisələr Amerika Birləşmiş Ştatlarının, Böyük Britaniyanın, Almaniyanın, İsveçin, Çexiyanın, Finlandiyanın və digər ölkələrin cəza-icra sistemlərinin tərkibinə daxildir.

SSRİ-yə daxil olan digər respublikalarda olduğu kimi, Azərbaycanda da məntəqə tipli cəzaçəkmə müəssisəsinin təşkilinın hüquqi əsası hələ 1963-cü ildə qoyulmuşdu. Belə ki, Azərbaycan SSR Ali Soveti Rəyasət Heyətinin 11 dekabr 1963-cü il tarixli Fərmanı ilə azadlıqdan məhrum edilmiş şəxslərin islah olunması və yenidən tərbiyələndirilməsi işinin daha da təkmilləşdirilməsi, cəzasının bir hissəsini çəkmiş və islah yoluna möhkəm qədəm qoymuş məhkumların saxlanması məqsədilə müvafiq növlü islah-əmək koloniyası təsis olunmuşdu. Sözügedən fərmana əsasən, azadlıqdan məhrum edilməklə cəzalarını ümumi, möhkəm və ciddi rejimli islah-əmək müəssisələrində çəkən, özünün nümunəvi davranışı ilə fərqlənən, əməyə vicdanla yanaşan, özfəaliyyət təşkilatlarında və öz kollektivinin ictimai həyatında iştirak edən məhkumlar məhkəmənin qərarına əsasən islah-əmək koloniya-məntəqələrinə–köçürmə yerlərinə (bundan sonra islah-əmək koloniya-məntəqəsi) keçirilə bilərdilər. Onu da qeyd etmək istərdik ki, cinayət qanunvericiliyində, habelə hüquq ədəbiyyatında islah-əmək koloniya-məntəqəsinə, yaxud məntəqə tipli cəzaçəkmə müəssisəsinə keçirilmə, cəzaçəkmə müəssisəsinin növünün dəyişdirilməsi kimi də xarakterizə edilir.

İslah-əmək koloniya-məntəqəsi, 1921-ci ildə pilot qaydada Rusiya Federasiyasında yaradılmış keçid növlü islah-əmək evlərinə oxşarlığı ilə diqqəti cəlb edir. Bir müddət sonra keçid islah-əmək evləri SSRİ-nin tərkibində olan digər respublikaların, o cümlədən Azərbaycan SSR-nin islah-əmək qanunvericiliyinə də daxil edilmişdi. Belə ki, 25 may 1925-ci il tarixli Azərbaycan SSR-nin İslah-Əmək Məcəlləsinin (bundan sonra Az. SSR İƏM) 46-cı maddəsində keçid islah-əmək evləri həbs yerlərinin, yəni azadlıqdan məhrum etmə yerlərinin bir növü kimi təsbit olunmuşdu. İstinad olunan məcəllənin 156-cı maddəsinə əsasən keçid islah-əmək evləri azadlıqdan məhrum etmə cəzasının bir hissəsini çəkmiş, əmək həyatına uyğunlaşma nümayiş etdirən, həmin vaxtlar qanunvericiliyə uyğun olaraq məhkəmələrin yanında fəaliyyət göstərən, Bölüşdürmə komissiyaları adlandırılan xüsusi qurum tərəfindən, cəzanın icrası şərtləri daha humanist olan yarımsərbəst rejim şəraitinə keçirilməsi məqsədəuyğun hesab edilmiş məhkumlar üçün nəzərdə tutulmuşdu. Keçid islah-əmək evlərinin əsas məqsədi müvafiq məhkumların azad həyata necə hazır olduqlarını müəyyən etmək idi. Həmin islah-əmək evlərində cəzanın icrası şərtləri digər həbs yerləri ilə müqayisədə bir qədər humanist olmuşdur. Sonralar keçid islah-əmək evləri SSRİ-də cəza siyasətinin sərtləşdirilməsi ilə əlaqədar 1929–1930-cü illərdə ləğv edilərək, digər növlü həbs yerlərinə çevrilmişdi [2, c. 180]. Keçid növlü islah-əmək evlərinin ömrü qısa müddətli olduğuna görə onlar Azərbaycan SSR-də təşkil edilməmişdi.

SSRİ-də islah-əmək koloniya-məntəqəsinin yaradılmasının bir neçə məqsədi var idi. Onların təşkili ilk növbədə azadlıqdan məhrum etmə cəzasının çəkilməsi rejiminin humanistləşdirilməsi məqsədi daşısa da, aşağıdakı əlavə hədəflər də göstərilirdi:

– ümumi, ciddi rejimli cəzaçəkmə müəssisələrində məhkumların qanuna itaətli davranışa həvəsləndirilməsi;

– məhkumun cəmiyyətdən uzun müddət təcrid edilməsi ilə əlaqədar yaranan mənfi nəticələrin bir qədər neytrallaşdırılması;

– cəzanın icrası prosesində məhkumların islahı ilə əlaqədar əldə olunmuş müsbət nəticələrin möhkəmləndirilməsi və onların azad cəmiyyətdə yaşayışa hazırlanması;

– cəzanın icrasının məqsədlərinə nail olunması [3, c. 350].

Lakin göstərilənlərdən əlavə, elan edilməyən daha bir məqsədi, yəni azadlıqdan məhrum edilmiş məhkumların ucuz əməyindən istifadə etməklə, onların SSRİ-də xalq təsərrüfatı sahələrində qarşıda duran vacib vəzifələrin həyata keçirilməsinə, habelə kifayət qədər gəlir gətirən ağır fiziki işlərə də cəlb edilməsini vurğulamaq lazımdır. Belə ki, qeyd olunanlara dövlət əhəmiyyətli tikintilərdə, o cümlədən Baykal–Amur magistral dəmir yolunun inşasında, o vaxtkı dövlətin xəzinəsinə hər il xeyli miqdarda xarici valyuta gətirən, lakin bir qayda olaraq, SSRİ-nin şimalında yaşayış üçün çox çətin, bəzi hallarda nəqliyyat çatımlığı kifayət qədər məhdud yerlərdəki meşələrdə ağac emalı işlərində əmək qabiliyyətli azadlıqdan məhrum edilmiş şəxslərin, o cümlədən islah-əmək koloniya-məntəqələrindəki məhkumların əməyindən geniş istifadə edilməsini misal gətirmək olar. Eyni zamanda, islah-əmək koloniya-məntəqələrinin, habelə həmin müəssisələrdə məhkumların saxlanması xərcləri digər növ islah-əmək koloniyaları ilə müqayisədə daha az maliyyə vəsaiti tələb edirdi [4, c. 202]. İlk növbədə Rusiya Federasıyasının ərazisində təşkil edilmiş həmin müəssisələrə SSRİ-yə daxil olan respublikalardan, o cümlədən Azərbaycandan da məhkumlar göndərilirdi. Onların məsafə baxımından Azərbaycan SSR-dən kifayət qədər uzaqlarda, bəzi hallarda isə, yaşayış yerlərindən xeyli kənarda, keçilməz ərazilərdə yerləşməsi, habelə məhkumlarla görüş məqsədilə səfərlərin heç də az olmayan vəsait tələb etdiyi səbəblərindən sözügedən müəssisələrdə cəza çəkənlərin qohumları ilə bilavasitə əlaqələrində ciddi

çətinliklər yaranırdı, onlar bəzi hallarda, demək olar ki, mümkünsüz olurdu. Bu da öz növbəsində məhkumların öz ailələri ilə normal ünsiyyətlərinin saxlanmasına mənfi təsir göstərirdi [5, p. 64].

Cəza siyasətinin humanistləşdirilməsi ilə əlaqədar SSRİ Ali Soveti Rəyasət Heyətinin SSRİ və müttəfiq respublikaların cinayət və islah-əmək qanunvericiliklərinin əsaslarına əlavə və dəyişikliklər edilməsinə dair 8 fevral mart 1977-ci il tarixli Fərmanına uyğun olaraq, Azərbaycan SSR Ali Soveti Rəyasət Heyətinin 28 mart 1977-ci il tarixli Fərmanı ilə ehtiyatsızlıqdan törədilmiş cinayətlərə görə ilk dəfə azadlıqdan məhrum etməyə məhkum edilən şəxslər üçün islah-əmək koloniya-məntəqəsinin yeni növü müəyyən edildi. Həmin müəssisələrin təşkilinin məqsədi məhkumların əməyindən istifadə edilməsilə yanaşı, ehtiyatsızlıqdan törədilmiş cinayətlərə görə ilk dəfə azadlıqdan məhrum edilmiş şəxsləri digər məhkumlardan ayırmaq, böyük ciddi ictimai təhlükə törətməyən belə kateqoriyalı məhkumları yarı azadlıq şəraitində islah və yenidən tərbiyə etmək, onları ağır, habelə təkrar cinayət törətmiş, sosial və mənəvi pozğunluğu yüksək olan digər şəxslərin mənfi təsirindən qorumaq olmuşdur [6, c. 55].

Bir müddət sonra SSRİ və müttəfiq respublikaların cinayət və islah-əmək qanunvericiliklərinin əsaslarına əlavə və dəyişikliklər edilməsi ilə bağlı SSRİ Ali Soveti Rəyasət Heyətinin 2 aprel 1985-ci il tarixli Fərmanına uyğun olaraq, Azərbaycan SSR Ali Soveti Rəyasət Heyətinin 16 may 1985-ci il tarixli Fərmanı ilə qəsdən törədilmiş, ağır olmayan cinayətlərə görə ilk dəfə beş ilədək azadlıqdan məhrum etməyə məhkum edilənlər üçün islah-əmək koloniya-məntəqəsinin daha bir növü müəyyən olunmuş və belə bir müəssisə Bakı şəhərinin ərazisində təşkil edilmişdi. Lakin həmin yeni növ islah-əmək koloniya-məntəqəsində cəza çəkən məhkumların sayının kifayət qədər az olması səbəbindən onlar azadlıqdan məhrum etmə yeri kimi SSRİ-yə daxil olan əksəriyyət respublikaların yeni cinayət qanunvericiliyinə, o cümlədən Azərbaycan Respublikasının 1999-cu ilin 30 dekabr tarixli yeni Cinayət Məcəlləsinə də daxil edilməmişdir. Eyni zamanda, sözügedən növlü məntəqə tipli cəzaçəkmə müəssisələri Rusiya Federasiyasının, Özbəkistanın, Moldova Respublikasının Cinayət məcəllələrində qalmaqdadır.

İslah-əmək koloniya-məntəqəsinin iki digər növü təcrübədə onlara bəslənən ümidləri ümumən doğrultmuş, buna görə də uzun müddətdir ki, onlar qanunvericilikdə öz yerlərini qoruyub saxlamışlar. Hər üç növ islah-əmək koloniya-məntəqəsində cəzanın icrası qayda və şərtləri Az. SSR İƏM-də eyni olmuş, müvafiq normalar sonradan demək olar ki, böyük dəyişikliklərə məruz qalmadan AR CİM-də də öz əksini tapmışdır.

XX əsrin 80-ci illərin sonunda Azərbaycanda ümumən dörd, onlardan üçü ölkənin Qarabağ regionunun ərazisində olmaqla, islah-əmək koloniya-məntəqəsi fəaliyyət göstərirdi. Həmin müəssisələrdə cəzanın icrası, məhkumların saxlanması üçün qanunvericiliyin tələblərinə uyğun olaraq zəruri şərait və infrastruktur yaradılmışdı. Həmin islah-əmək koloniya-məntəqələrində məhkumlar ictimai faydalı əməklə təmin olunmuş, onlar SSRİ-nin Dövlət Plan Komitəsi tərəfindən müəyyən edilmiş müvafiq iş bölgüsünə uyğun olaraq müxtəlf, o cümlədən kənd təsərrüfatı ilə bağlı sahələrdə, habelə üzümçülükdə istifadə olunan dəmir-beton dirəklərin istehsalı işinə cəlb edilmişdilər. Lakin qeyd olunmalıdır ki, həmin müəssisələrdə ölkə məhkəmələri tərəfindən cəzasının çəkilməsi yeri islah-əmək koloniya-məntəqəsi təyin edilmiş məhkumların bir hissəsi cəza çəkirdi, digər belə şəxslər isə, yuxarıda göstərildiyi kimi digər respublikalara, bir qayda olaraq Rusiya Federasiyasının ərazisindəki müvafiq növlü müəssisələrə göndərilirdilər.

1988-ci ilin əvvəlində Ermənistanın Azərbaycanın tarixi torpaqlarına açıq formada ərazi iddiaları, etnik zəmində təxribatları, terror əməlləri ilə başlamış, qısa müddət sonra ciddi hərbi münaqişəyə cevrilmiş hadisələrlə bağlı Qarabağda fəaliyyət göstərən islah-əmək koloniya-məntəqələri təhlükəsizlik baxımından məhkumlarla birlikdə respublikanın digər ərazilərinə köçürülmüşdü [7, c. 325]. Eyni zamanda, həmin vaxtlar SSRİ-nin süqutu, Azərbaycanın öz müstəqilliyini bərpa etməsi ilə əlaqədar sabiq ittifaqa daxil olan digər respublikaların ərazisindəki islah-əmək koloniyalarında, o cümlədən islah-əmək koloniya-məntəqələrində cəza çəkən azərbaycanlı məhkumların kütləvi şəkildə ölkəyə qaytarılması ilə bağlı, habelə yeni məhkəmə qərarlarına uyğun olaraq məhkum edilmiş və ya digər müəssisələrdən keçirilmiş müvafiq şəxslərin qanunvericiliyə uyğun yerləşdirilməsində ciddi problemlər yaranmışdı. Məsələnin həlli məqsədilə qısa müddətdə ölkədə yeni islah-əmək koloniyalarının, o cümlədən bir neçə islah-əmək koloniya-məntəqələrinin təşkili ilə bağlı qərarlar qəbul edilmişdi [8, Səh. 196–197]. Lakin mövcud islah-əmək koloniya-məntəqələrinin dislokasiya yerinin dəyişdirilməsi, habelə yenilərinin yaradılması zamanı Azərbaycanın müharibə şəraitində olması, Ermənistan ərazisində daimi yaşayan azərbaycanlıların kütləvi şəkildə deportasiyası, ölkənin torpaqlarının bir hissəsinin işgalı nəticəsində on şəhər və rayondan öz yaşayış yerlərini tərk etmiş məcburi köçkünlərin sayının kifayət qədər çox olması, habelə ölkə iqtisadiyyatının çətin vəziyyəti ilə əlaqədar, onların islah-əmək qanunvericiliyinin tələblərinə cavab verən şəraitdə fəaliyyət göstərməsi üçün zəruri infrastrukturun tam təşkili imkan xaricində olmuşdur. Sonrakı dövrlərdə, istər islah-əmək koloniya-məntəqələrində, istərsə məntəqə tipli cəzaçəkmə müəssisələrində qanunvericiliyə uyğun şəraitin yaradılması məqsədilə dövlət büdcəsindən vəsait ayrılması ilə bağlı edilmiş müraciətlər müsbət nəticə vermədiyindən, problemlər öz həllini tapmamışdır. Nəticədə, həmin müəssisələrdə cəzanın icrasının qanunvericiliyə uyğun həyata keçirilməsi mümkün olmamış, maddi-məişət şəraitində, ictimai faydalı əməyə cəlb edilmədə, habelə qidalanmadakı çətinliklər nəticəsində məhkumların cəzanın yayınması, yeni təkrar cinayətlərin törətməsi hallarının artması tendensiyası müşahidə edilmişdir. Eyni zamanda, yaranmış vəziyyət ictimaiyyətin, xüsusilə müvafiq məhkumların törətdikləri cinayətlərdən zərərçəkmiş

şəxslərin və onların yaxınlarının haqlı narazılıqlarına da səbəb olmuşdur.

Problemin həllinə kömək məqsədilə, yuxarıda qeyd olunduğu kimi, Azərbaycan Respublikasının 31 may 2011-ci il tarixli Qanunu ilə AR CİM-ə də edilmiş dəyişikilklərlə məntəqə tipli cəzaçəkmə müəssisələrinə digər müəssisələrdən keçirilən məhkumların dairəsi məhdudlaşdırılmış, habelə sözügedən məcəllənun 119-cu maddəsi yeni redaksiyada verilməklə, cəzanın icrası şərtləri bir qədər sərtləşdirilmişdir. Belə ki, müvafiq maddənin yeni mətninin sabiq redaksiyadan əsas fərqi, ilk növbədə, cəza çəkən məhkumların birmənalı olaraq məntəqə tipli cəzaçəkmə müəssisəsinin yataqxanasında yaşaması, onların yalnız müəssisə daxilində sərbəst hərəkət etmələrinə icazə verilməsi ilə bağlıdır. Göstərilən dəyisiklikliyə qədər məhkumlar müəssisənin yerləşdiyi ərazidə də sərbəst hərəkət edə bilərdilər, habelə mənzil şəraiti olduqda, onlar müdiriyyətin icazəsi ilə cəzaçəkmə müəssisəsinə yaxın ərazidə öz ailələri ilə birlikdə yaşaya, yaşayış yeri əldə edə və şəxsi təsərrüfat da yarada bilərdilər. Hazırda isə, məhkumlar məntəqə tipli cəzaçəkmə müəssisəsini, yalnız ona yaxın ərazidə işə düzəldikləri və ya ali, orta ixtisas, peşə təhsili müəssisələrində təhsil aldıqları halda, müdiriyyətin razılığı ilə və Azərbaycan Respublikasının ərazi hüdudlarında olmaqla, sutkada on iki saatdan artıq olmayan müddətdə tərk edə bilərlər. Bu halda müəssisənin müdiriyyəti tərəfindən hər bir məhkumla bağlı qərar qəbul edilir, onun məntəqə tipli cəzaçəkmə müəssisəsindən çıxması və geriyə qayıtması vaxtı fərdi tərtib olunan cədvəllə müəyyənləşdirilir. Eyni zamanda, əvvəllər məhkumların yemək, tibbi-sanitariya və digər təminatları özləri tərəfindən, yəni öz vəsaitləri hesabına həyata keçirilirdi. Cəzanın icrası şərtlərinin dəyişdirilməsi ilə bağlı müvafiq məhkumların kommunal, yemək, maddi-məişət, tibbi-sanitariya və digər təminatlarının artıq dövlət hesabına həyata keçirilməsi nəzərdə tutulmuşdur. Habelə, müvafiq dəyişikliyə uyğun olaraq məhkumların yaxın qohumları və digər şəxslərlə qısa və uzun müddətli görüşləri məntəqə tipli cəzaçəkmə müəssisəsinin ərazisində həyata keçirilir. Əvvəllər isə, məhkumlar görüş huquqlarını müəssisədən kənarda da, yəni onun yerləşdiyi inzibati ərazidə və sərbəst şəkildə həyata keçirə bilərdilər.

Eyni zamanda, AR CİM-in 105-ci maddəsinə uyğun olaraq məntəqə tipli cəzaçəkmə müəssisələrində cəza çəkən məhkumlara həvəsləndirmə tədbiri qaydasında istirahət və bayram günlərini müəssisəsinin ərazisindən kənarda keçirməyə icazə verilə bilər. Habelə, AR CİM-in 107-ci maddəsində, cəzanın icrası qaydalarını qərəzli pozan məhkumlara, bir ay müddətində məntəqə tipli cəzaçəkmə müəssisəsindən kənara çıxmağın və ya üç ay ərzində istirahət və bayram günlərini cəzaçəkmə müəssisəsindən kənarda keçirməyin qadağan edilməsi kimi tənbeh tədbirlərinin tətbiq edilməsi də nəzərdə tutulmuşdur.

Qeyd olunanlarla yanaşı, məhkumların sözügedən müəssisələrdə mühafizəsiz, lakin nəzarət altında saxlanılmaları, məhdudiyyət qoyulmadan qohumları, digər şəxslərlə yazışmaları, görüşləri, bağlama, sovqat və ya banderol almaları, məişətdə istifadə edilən adi geyim daşımaları, özlərində pul və qiymətli əşyalar gəzdirmələri, puldan qeyri-məhdud istifadə etmələri ilə bağlı normalar dəyişikliklərə məruz qalmamış, onlara hər gün, müddəti on beş dəqiqə olmaqla, bir telefon danışığı və ya videogörüş hüququ da verilmişdir. AR CİM-ə edilmiş sözügedən sonuncu dəyişiklik, məntəqə tipli cəzaçəkmə müəssisələrinin CÇM DİQ-lə müəyyən olunmuş quruluşunun təkmilləşdirilməsini, yəni gündəlik qidalanmanın təşkili üçün ərzaq anbarının, mətbəxin, yeməkxananın, habelə görüş otaqlarının (qısa və uzun müddətli), tibb-sanitariya hissəsinin, kitabxananın, ticarət köşkünün, camaşırxanın, idman meydançasının və digər zəruri obyektlərin təşkilini, yaxud yenidən qurulmasını, habelə işçi heyətinin sayının, məhkumların saxlanma xərclərinin artmasını şərtləndirmişdir. Eyni zamanda, məhkumların əmək hüquqlarının həyata keçirilməsi ilə əlaqədar, yəni məntəqə tipli çəzaçəkmə müəssisələrinin nəzdində və ya onun yaxınlığında istehsal sahələrinin yaradılması, yaxud cəza çəkənlərin yaxın ərazilərdə digər müəssisə və təşkilatlarda işlə təmin edilməsi məsələsinin həlli ilə bağlı aidiyyəti tədbirlərin görülməsi zərurəti də yaranmışdı. AR CİM-ə edilmiş dəyişikliyin, onunla bağlı dövlət başçısının 25 iyun 2011-ci il tarixli sərəncamının, habelə Nazirlər Kabinetinin müvafiq qərarının icrası ilə bağlı məntəqə tipli cəzaçəkmə müəssisələrində zəruri tikinti və yenidənqurma işlərinin həyata keçirilməsi, onların maddi-texniki bazasının təkmilləşdirilməsi ilə əlaqədar Ədliyyə nazirliyi tərəfindən ətraflı təhlillər aparılmış, görülməli insa-təmir işlərinin həcmi, təchizat və təminatla bağlı məsələlərin həlli, ehtiyac duyulan əlavə ştat vahidləri ilə bağlı təkliflər hazırlanmış, habelə tələb olunan, heç də az olmayan maliyyə vəsaitinin ilkin məbləği müəyyən edilmişdi. Lakin aidiyyəti dövlət orqanlarına edilmiş müraciətlərə baxmayaraq, maliyyə vəsaiti ayrılmamış, buna görə də problemlər öz həllini tapmamışdır.

Məntəqə tipli cəzaçəkmə müəssisələrində mövcud problemlərin çözülməsi üçün kifayət qədər böyük məbləğdə maliyyə vəsaitinin ayrılması ilə bağlı çətinlikləri nəzərə alaraq, onun miqdarının azaldılması məqsədilə Ədliyyə nazirliyi tərəfindən AR CM-in 76-cı, AR CİM-in 70 və 119-cu maddələrinə bir sıra dəyişikliklər edilməsi ilə bağlı təkliflər də hazırlanmışdı. Təkliflərdə, cəzaçəkmə müəssisələrindən keçirilmiş məhkumlar üçun nəzərdə tutulmuş məntəqə tipli cəzaçəkmə müəssisələrinin ləğv edilməsi, həmin kateqoriyalı məhkumların AR CM-in 76-ci maddəsində təsbit edilmiş və ya digər məhkumlarla müqayisədə bir qədər imtiyazlı şərtlərlə cəzadan şərti olaraq vaxtından əvvəl azad edilməsi nəzərdə tutulmuşdu. Eyni zamanda, ehtiyatsızlıqdan törədilmiş cinayətlərə görə məhkum olunmuş şəxslər üçün məntəqə tipli cəzaçəkmə müəssisəsində cəzanın icrası şərtlərini humanistləşdirməklə, onların müəyyən qədər dəyişdirilməsi də təklif edilmişdi. Lakin təkliflər məntiqi sonluğa yetmədiyindən, vəziyyət dəyişməmiş və çətinliklər olduğu kimi qalmışdır. Eyni zamanda, Naxçıvan Muxtar Respublikasında penitensiar kompleksin, yəni qarışıq rejimli cəzaçəkmə müəssisəsinin tikintisi zamanı onun bilavasitə yaxınlığında cəzaların icrası qanunvericiliyinin tələblərinə cavab verən yeni məntəqə tipli cəzaçəkmə müəssisəsi inşa edilmişdir [9, c. 5].

Məntəqə tipli çəzaçəkmə müəssisələrində cəza çəkən şəxslərin sayı ilə bağlı qeyd olunmalıdır ki, onlar müxtəlif illərdə Azərbaycan Respublikasının cəzaçəkmə müəssisələrindəki məhkumların ümumi sayının təxminən 5–15 %-ni təşkil etmişdir. Müvafiq şəxslərin böyük əksəriyyəti ehtiyatsızlıqdan törədilmiş cinayətlərə görə, xüsusilə AR CM-in 263, 263-1-ci maddələrində nəzərdə tutulmuş yol hərəkəti və nəqliyyat vasitələrinin istismarı qaydalarını pozulması ilə əlaqədar əməllərə görə məhkum edilmişlər olmuşdur. İstinad edilən maddələrdə göstərilmiş ictimai təhlükəli əməlləri törətmiş şəxslərin artması, ehtiyatsızlıqdan törədilmiş cinayətlərə görə məhkum olunmuş şəxslər üçün nəzərdə tutulmuş məntəqə tipli cəzaçəkmə müəssisəsində cəza çəkənlərin də sayının ardıcıl olaraq artımına səbəb olmuşdur. Eyni zamanda, ölkədə müstəqillik illərində, o cümlədən 2001–2025-ci illərdə qəbul edilmiş səkkiz amnistiya aktının məntəqə tipli cəzaçəkmə müəssisələrində, xüsusilə ehtiyatsızlıqdan törədilmiş cinayətlərə görə cəza çəkən şəxslərə də tətbiq edilməsinin nəzərdə tutulması, sözügedən məhkumların sayının azalmasına zəmin yaratmışdır. Belə ki, 2013, 2016 və 2021-ci illərdə qəbul edilmiş üç amnistiya aktının icrası prosesində ehtiyatsızlıqdan törədilmiş cinayətlərə görə məhkum edilmiş 4 min 400-dən çox şəxs cəza çəkməkdən azad olunmuşdu ki, onların da böyük əksəriyyətini məntəqə tipli cəzaçəkmə müəssisələrində saxlanılan məhkumlar təşkil etmişdi.

Azərbaycan Respublikasının Milli Məclisinin 19 dekabr 2025-ci il tarixli "Konstitusiya və Suverenlik İli" münasibətilə qəbul etdiyi sonuncu amnistiya aktı ümumən 22 min 935 təqsirləndirilən şəxsə və məhkuma tətbiq olunmuşdur ki, onların da 5 min 348 nəfəri azadlıqdan məhrum etmə cəzasından azad edilmişdir. Cəzaçəkmə müəssisələrindən azad olunanların təxminən 20 %-ni məntəqə tipli cəzaçəkmə müəssisələrində cəza çəkən məhkumlar təşkil etmişdir [10]. Eyni zamanda, Azərbaycan Respublikası Prezidentinin əfvetmə aktları məntəqə tipli cəzaçəkmə müəssisələrində cəza çəkən məhkumlara da tətbiq olunmuşdur. Belə ki, təkcə 2011–2025-ci illər ərzində imzalanmış 23 əfvetmə aktı, ümumilikdə 5 min 30 məhkuma şamil edilmişdir. Onlardan 1 min 206 nəfəri ehtiyatsızlıqdan törədilmiş cinayətlərə görə cəzadan azad olunmuşdur ki, həmin şəxslərin də bir hissəsini məntəqə tipli cəzaçəkmə müəssisələrində cəza çəkən məhkumlar təşkil etmişdir [11, c. 37]. Nəticədə, müvafiq illərdə, habelə 2026-cı ilin birinci yarısında sözügedən cəzaçəkmə müəssisələrində məhkumların sayı xeyli azalmışdır.

Lakin qeyd olunanlara baxmayaraq, yaranmış vəziyyət, yəni məntəqə tipli cəzaçəkmə müəssisələrində cəzanın icrasının qüvvədə olan qanunvericiliyə uyğun icrasının təmin edilməsi problemi ölkə rəhbərliyini də narahat etmişdir. Buna görə də Azərbaycan Respublikası Prezidentinin "Penitensiar sahədə fəaliyyətin təkmilləşdirilməsi, cəza siyasətinin humanistləşdirilməsi və cəmiyyətdən təcridetmə ilə əlaqədar olmayan alternativ cəza və prosessual məcburiyyət tədbirlərinin tətbiqinin genişləndirilməsi barədə" 10 fevral 2017-ci il tarixli Sərəncamında cəzaların icrası sahəsində mövcud nöqsan və problemlər arasında məntəqə tipli cəzaçəkmə müəssisələrinin normal fəaliyyətinin təmin olunmadığı da qeyd edilmişdir. Sərəncamda sözügedən müəssisələrdə cəzanın AR CİM-də nəzərdə tutulmuş qaydada çəkilməsinin və məhkumlar tərəfindən rejim qaydalarına ciddi riayət olunmasının təmin edilməsi, bu sahədə korrupsiyaya şərait yaradan və digər neqativ halların qarşısının alınması üçün tədbirlər görülməsi ilə əlaqədar tapşırıqlar verilmişdir. Eyni zamanda, Azərbaycan Respublikasının Nazirlər Kabinetinə məhkumların məntəqə tipli cəzaçəkmə müəssisələrində saxlanmasına və təminatına dair AR CİM-in müddəalarına riayət olunmasının təmin edilməsi məqsədilə tikinti və təchizat işlərinin yerinə yetirilməsi üçün maliyyə vəsaitinin ayrılmasının mümkünlüyünə baxılması da tapşırılmışdır. Sözügedən sərəncamda dövlət başçısının məntəqə tipli cəzaçəkmə müəssisələri ilə əlaqədar verdiyi tapşırıqlara uyğun olaraq görülməli aidiyyəti tədbirlər "Azərbaycan ədliyyəsinin inkişafına dair 2019–2023-cü illər üçün Dövlət Proqramı"nın icrası üzrə Tədbirlər Planına da daxil edilmiş, habelə, həmin Planda müvafiq növlü müəssisəyə keçirilmə institutunun təkmilləşdirilməsi üzrə təkliflərin hazırlanması ilə bağlı tapşırıq da öz əksini tapmışdı. Dövlət başçısının sərəncamının, ölkənin Nazirlər Kabinetinin müvafiq qərarının, habelə istinad edilən Dövlət Proqramının aidiyyəti bəndlərinin icrasının təmin olunması məqsədilə Ədliyyə nazirliyi tərəfindən xüsusi komissiya yaradılmış, bütün məntəqə tipli cəzaçəkmə müəssisələri üzrə ətraflı təhlillər aparılmış, beynəlxalq təcrübə öyrənilməklə onların fəaliyyətinin AR CİM-in tələblərinə uyğun təşkili məqsədilə təkliflər hazırlanmış və zəruri tədbirlərin həyata keçirilməsi ilə əlaqədar maliyyə vəsaitinin ayrılması üzrə yenidən müraciətlər olunmuşdur. Habelə, verilmiş tapşırığa uyğun olaraq məntəqə tipli cəzaçəkmə müəssisələrinə keçirilmə, habelə həmin müəssisələrdə cəzanın icrası şərtlərinin dəyişdirilməsi ilə bağlı təkliflər də hazırlanmışdı. Belə ki, ölkənin ümumi rejimli cəzaçəkmə müəssisələrinin nəzdində, təcrid olunmuş qaydada və ya onlara bilavasitə bitişik ərazilərdə məntəqə tipli cəzaçəkmə müəssisələri əvəzinə sosial reabilitasiya sahələrinin yaradılması ilə əlaqədar AR CM, AR CİM-ə dəyişikliklər edilməsi nəzərdə tutulmuşdu. Sözügedən reabilitasiya sahələrində cəzanın icrası, məhkumların saxlanması üçün müvafiq cəzaçəkmə müəssisələrindəki mövcud infrastrukturun imkanlarından, o cümlədən nəzarətin həyata keçirilməsi, habelə qidalanma və digər məsələlərin həlli ilə əlaqədar istifadə edilə bilərdi. Eyni zamanda, Ədliyyə nazirliyinin rəhbərliyinin tövsiyəsinə əsasən, məhkumların məntəqə tipli cəzaçəkmə müəssisələrinə keçirilməsi əvəzinə, onların cəzadan şərti olaraq vaxtından əvvəl azad edilməsinə üstünlük verilmiş, nəticədə, müvafiq tipli müəssisələrdə cəza çəkən şəxslərin sayı xeyli azalmışdır. Qeyd olunanlarla yanaşı, Ədliyyə nazirliyi Penitensiar xidmətinin fəaliyyətinin təşkili ilə əlaqədar hər il dövlət büdcəsindən ayrılmış vəsait çərçivəsində sözügedən müəssisələrdə mövcud maddi-məişət şəraitinin yaxşılaşdırılması ilə bağlı müəyyən tədbirlər də görülmüş, habelə korrupsiya və digər neqativ halların qarşısının alınması üzrə səylər gücləndirilmişdir. Lakin

görülmüş işlərə, habelə dövlət başçısı tərəfindən verilmiş tapşırıqlardan doqquz ildən çox müddət keçməsinə baxmayaraq, qeyd olunan müəssisələrlə bağlı mövcud problemlər, ilk növbədə, maliyyə vəsaitinin ayrılmaması səbəbindən hələ də öz həllini tapmamışdır. Məntəqə tipli cəzaçəkmə müəssisələrinin fəaliyyətinin müvafiq qanunvericiliyə tam cavab verməmiyi, bununla bağlı zəruri tədbirlərin görülməsinin vacibliyi Azərbaycan Respublikasının İnsan Hüquqları üzrə Müvəkkilinin (Ombudsmanın) İşgəncələr əleyhinə Milli Preventiv Mexanizm mandatı çərçivəsində müvafiq Qrupunun fəaliyyəti ilə əlaqədar müxtəlif illər üzrə hazırlanmış hesabatlarında da öz əksini tapmışdır [12].

Eyni zamanda, nəzərə almaq lazımdır ki, fəaliyyətinin təşkili ilə əlaqədar 2012–2025-ci illərdə Ədliyyə nazirliyinin Penitensiar xidmətinə dövlət büdcəsindən hər il artmaqla, ümumilikdə, təminən 1,6 milyard manatdan çox vəsait ayrılmışdır. Habelə, Azərbaycan Respublikası Prezidentinin sərəncamları ilə təsdiq edilmiş 2009–2013, 2019–2023-cü illər üçün ədliyyə orqanlarının inkişafı ilə bağlı iki Dövlət proqramında nəzərdə tutulmuş, cəzaları icra edən müəssisə və orqanların fəaliyyətinin təkmilləşdirilməsi ilə bağlı tədbirlər çərçivəsində məhkumlarla davranışa dair beynəlxalq standartlara uyğun inşa edilən, 2012, 2022–2024-cü illərdə Bakı, Şəki, Lənkəran şəhərlərində dörd yeni müasir penitensiar kompleksin, yəni müxtəlif növlü müəssisələrdən ibarət qarışıq rejimli cəzaçəkmə müəssisələrinin istismara verilməsi, habelə Gəncə şəhəri yaxınlığında daha bir böyuk penitensiar kompleksin inşası ilə bağlı dövlət büdcəsindən kifayət qədər böyük maliyyə ayrılmışdır [13, c. 39, 14, c. 13]. Onu da vurgulamaq lazımdır ki, müvafiq illərdə ölkədə əhalinin, xüsusi ilə məcburi köçkün və qaçqınların sosial, maddi-məişət və digər problemlərinin həlli, Azərbaycan Respublikası Silahlı Qüvvələrinin modernləşdirilməsi, habelə dövlət əhəmiyyətli digər məsələlərin həlli istiqamətində hər il dövlət budcəsində heç də az olmayan məbləğlərdə vəsaitlər nəzərdə tutulmuşdu. Fikrimizcə, Azərbaycan Respublikasının Prezidenti məhz qeyd edilən səbəblər baxımından, yuxarıda istinad olunan sərəncamında məntəqə tipli cəzaçəkmə müəssisələrində tikinti, təchizat işlərinin və digər tədbirlərin yerinə yetirilməsi, zəruri infrastrukturun təşkili ilə əlaqədar maliyyələşmədə çətinliklər olduğunu nəzərə alaraq, sözügedən müəssisələrdə görüləsi işlərlə əlaqədar dövlət büdcəsindən vəsaitin ayrılmasının mümkünlüyünə baxılması ilə bağlı tapşırıq vermişdir.

Eyni zamanda, Azərbaycan Respublikasının düşmən tapdağı altında olmuş ərazilərinin bərpası, yenidən qurulması, sonrakı mərhələlərdə dayanıqlı inkişafına nail olunması hədəflərinə uyğun islərə, habelə Azərbaycan Respublikası Prezidentinin 16 noyabr 2022-ci il tarixli Sərəncamı ilə təsdiq edilmiş "Azərbaycan Respublikasının işğaldan azad edilmiş ərazilərinə Böyük Qayıdışa dair I Dövlət Proqramı"nın icrası ilə bağlı müxtəlif təyinatlı və genişmiqyaslı tədbirlərin həyata keçirilməsinə 2020–2025-ci illərdə 22 milyard manatdan çox pul xərclənməsini, dövlət büdcəsindən 2026-cı ildə görüləcək müvafiq işlərə daha 3,5 milyard manat yönəldilməsini [15], habelə eyni məqsədlə ikinci Dövlət Proqramının hazırlanmasını və həyata keçiriləcək tədbirlərin xeyli maliyyə tələb edəcəyini də nəzərə almaq vacibdir.

Yuxarıda göstərilənlərə istinadən, məntəqə tipli cəzaçəkmə müəssisələrinin fəaliyyətində mövcud olan çətinliklərin aradan qaldırılmasının hazırkı dövrdə də kifayət qədər aktuallıq kəsb etdiyini, habelə dövlət başçısının müvafiq sərəncamda verdiyi tapşırıqların icrasının vacibliyini vurğulayaraq, arasdırılan məsələ ilə əlaqədar əvvəllər hazırlanmış təklifləri də nəzərə alaraq, problemin aşağıdakı kimi həllini daha məqsədəuyğun hesab edirik. Belə ki,

– ya sözügedən müəssisələrin sayını azaltmaqla, onların cəzaların icrası qanunvericiliyində nəzərdə tutulmuş normalara uyğunlaşdırılmasının təmin edilməsi ilə bağlı lazımi tədbirlərin görülməsi;

– yaxud həmin müəssisələri ləğv etməklə, müvafiq şəxslərə alternativ cəzaların tətbiqi imkanının, habelə umumi rejimli cəzaçəkmə müəssisələrində aidiyyəti məhkumlara cəzanın yumşaldılması və yaxud cəzadan azad edilmə ilə əlaqədar əlavə imtiyazların təqdim olunması təklif edilir.

Təkliflərimizi açıqlayaraq, qeyd etmək istərdik ki:

1) Məntəqə tipli cəzaçəkmə müəssisələrin birləşdirilməsi və onların yerləşdirmə hədlərinin (limitinin) iki-üç dəfə artırılması məqsədəuyğun olardı. Belə yanaşma, az sayda məntəqə tipli cəzaçəkmə müəssisələrində qanunvericilikdə təsbit olunan şəraitin, zəruri infrastrukturun təşkili üçün tələb olunan maliyyə vəsaitinin məbləğinin xeyli azalmasına kömək edə bilərdi. Məntəqə tipli cəzaçəkmə müəssisələrinin sayının azaldılması ilə bağlı təcrübə artıq mövcuddur. Belə ki, hələ 2020-ci ildə Özbəkistanda məntəqə tipli cəzacəkmə müəssisəsinə göndərilmə əvəzinə cəzadan şərti olaraq vaxtından əvvəl azad etmə, cəzanın çəkilməmiş hissəsini daha yüngül cəza növü ilə əvəz etmə institutlarından daha geniş istifadə olunması, habelə müvafiq kateqoriyalı məhkumlara azadlıqdan məhrum etmə əvəzinə alternativlər tətbiq edilərək, onların probasiya nəzarətinə verilməsi, bununla da sözügedən müəssisələrin sayının xeyli azadılması məqsədəuyğun hesab edilmiş və həmin qərarın icrası davam etməkdədir [16]. Fikrimizcə, məntəqə tipli cəzaçəkmə müəssisələrinin sayının azaldılması təqdirində, cəzanın icrası və islah prosesi üçün xüsusi əhəmiyyət kəsb edən bir məsələnin həlli, yəni məhkumların əhatəli şəkildə ictimai faydalı əməklə təmini məqsədilə, bir qayda olaraq, xüsusi təhsil, peşə və ixtisas hazırlığı tələb etməyən kənd təsərrüfatı ilə bağlı işlərə cəlb edilməsi daha məqsədəuyğun olardı. Belə yanaşmaya digər dövlətlərin təcrübəsində də rast gəlinir. Qeyd olunanlara istinadən məntəqə tipli cəzaçəkmə müəssisələrinin Azərbaycan Respublikasının yuxarıda göstərilən fəaliyyət sahəsi üçün daha əlverişli regionlarında təşkilini daha məqbul hesab edirik.

Eyni zamanda, ümumi rejimli cəzaçəkmə müəssisələrindən keçirilən məhkumlar üçün nəzərdə tutulmuş məntəqə tipli cəzaçəkmə müəssisələrində məhkumların sayının o qədər də çox olmadığını nəzərə alaraq, onların ləğv edilməsi, məsələnin daha asan çözülməsinə əlavə zəmin yaradardı. Müzakirə edilən problemin təklif edilən həlli yolu, qüvvədə olan AR

CİM-in tələblərindən irəli gəlməklə yanaşı, ölkə başçısının 10 fevral 2017-ci il tarixli sərəncamında verilmiş müvafiq tapşırıqların icrasını təmin edə bilərdi.

2) Məntəqə tipli cəzaçəkmə müəssisələrinin hər iki növünun ləğvinə gəldikdə, ilk növbədə, ehtiyatsızlıqdan törədilmiş cinayətlərə görə məsuliyyəti nəzərdə tutan AR CM-in Xüsusi hüssəsinin müvafiq maddələrinin, xüsusilə həmin məcəllənin 263.2, 263.3-cü, habelə 263-1.1–263-1.3-cü maddələrinin sanksiyalarına azadlıqdan məhrum etmə cəzası ilə yanaşı digər, yəni azadlığın məhdudlaşdırılması cəzasının da əlavə olunmasını təklif edirik. Eyni zamanda, müvafiq cinayətlərin bəzilərinin ağır nəticələrə səbəb olduqlarını nəzərə alaraq, azadlığın məhdudlaşdırılması cəzasının tətbiq edilmə müddətini yeddi ilədək artırılması daha məqsədəuyğun olardı. Belə yanaşma, məhkəmələrə sözügedən şəxslərə cəza təyini zamanı azadlıqdan məhrum etmə cəzası ilə yanaşı digər və daha məqbul alternativ seçim imkanı verə bilərdi. Düşünürük ki, bu da öz növbəsində, son illərdə ölkədə tətbiqi kifayət qədər yüksək olan müəyyən müddətə azadlıqdan məhrum etmə cəzasının, o cümlədən ehtiyatsızlıqdan törədilmiş cinayətlərə görə də tətbiqini azalda bilərdi [17, p. 13]. Eyni zamanda, azadlığın məhdudlaşdırılması cəzası ilə əlaqədar qanunvericiliklə müəyyən olunan məhdudiyyətlərin dairəsini bir qədər genişləndirmək və sərtləşdirmək də məqbul olardı**.** Belə ki, müəyyən istisnalar nəzərə alınmaqla, məhkumların üzərinə AR CM-in 52-1-ci maddəsində nəzərdə tutulmuş vəzifələrdən əlavə, istirahət və bayram günləri, işləyənlərə isə, əmək məzuniyyəti müddətində yaşayış yerini umumiyyətlə tərk etməmək, həftədə bir neçə dəfə telefon danışığı vasitəsi ilə cəzanı icra edən orqana olduğu yer barədə məlumat verməklə qeydiyyatdan keçmək, habelə məhkumun azadlığını məhdudlaşdıra bilən digər vəzifələr də qoyula bilərdi. Hesab edirik ki, ehtiyatsızlıqdan törədilmiş cinayətlərə görə məhkumlarla azadlıqdan məhrum etmə cəzası əvəzinə digər cəzanın, yəni azadlığın məhdudlaşdırılmasının mümkün tətbiqi, dövlət başçısının cəmiyyətdən təcrid etmə ilə bağlı olmayan alternativ cəza tədbirlərinin tətbiqinin genişləndirilməsi, azadlıqdan məhrum etmənin təyininə qənaətlə yanaşılması, cəzaçəkmə müəssisələrinin yüklənməsinin qarşısının alınması, həmin yerlərdə saxlanılan şəxslərin sayının azaldılması ilə əlaqədar 10 fevral 2017-ci il tarixli sərəncamında verdiyi müvafiq tapşırıqlarla da uyğunluq təşkil edərdi.

Habelə, sözügedən müəssisəyə ümumi rejimli cəzaçəkmə müəssisələrindən keçirilmə əvəzinə, məhkumların cəzadan şərti olaraq vaxtından əvvəl azad edilməsinə üstünlük verilərək, AR CM-in 76-cı maddəsinə dəyişikliklər olunmasını, yəni azad edilmə üçün qanunla çəkilməsi tələb edilən müvafiq müddətin bir qədər azaldılmasını, yaxud həmin məhkumların cəzalarının daha yüngül cəza növü ilə əvəz edilməsi ilə əlaqədar AR CM-in 77-ci maddəsində təsbit edilmiş müvafiq institutun ilk dəfə ağır cinayətlərə görə məhkum edilmiş şəxslərə də tətbiqi məsələsinin nəzərdən keçirilməsini vacib hesab edirik [18, c. 81]. Məntəqə tipli çəzaçəkmə müəssisələrinin ləğvi, azadlıqdan məhrum etmə yerlərinin saxlanmasına ayrılan, o qədər də az olmayan maliyyə vəsaitinə qənaət edilməsinə zəmin yarada bilərdi.

Eyni zamanda, düşünürük ki, alternativ tədbirlər görülmədən məntəqə tipli çəzaçəkmə müəssələrinin, ümumiyyətlə ləğv edilməsi də düzgün olmazdı. Belə olan təqdirdə, bu ilk növbədə, hər il heç də az olmayan sayda ilk dəfə ehtiyatsızlıqdan, xüsusilə yol hərəkəti və nəqliyyat vasitələrinin istismarı qaydalarını pozulması ilə əlaqədar cinayətlərə görə məhkum olunan şəxslərin, bir qayda olaraq daha ciddi rejim qaydaları ilə fəaliyyət göstərən ümümi rejimli cəzaçəkmə müəssisələrinə göndərilməsi ilə nəticələnə bilərdi. Bu da dövlətimizdə müstəqillik illərində həyata keçirilən humanist cəza siyasəti ilə müəyyən uyğunsuzluq təşkil edir, müvafiq məhkumlara münasibətdə cəzanın icrası qaydalarının şərtləşməsinə, məhkumların sayının, habelə onların saxlanması ilə bağlı ayrılan maliyyə vəsaitinin artmasını şərtləndirərdi.

Verilmiş təkliflərin hər hansı birinin qəbul olunması ilə bağlı Azərbaycan Respublikasının Cinayət və Cəzaların İcrası məcəllələrinə müvafiq dəyişikliklər edilməsi zərurəti yaranacaqdır. Araşdırılan məsələnin həlli ilə bağlı təkliflərimiz ideal olmasa da, onlar fikrimizcə, istər qanunvericiliyin humanistləşdirilməsi, istərsə də maliyyə tutumu baxımından mümkün və daha məqsədəuyğundur. Onu da vurğulamaq istərdik ki, məntəqə tipli çəzaçəkmə müəssisələrində cəzanın icrası qaydalarının təkmilləşdirilməsi, həmin müəssisələrdəki məhkumlara elektron nəzarət vasitələrinin tətbiqinin nəzərdə tutulması ilə bağlı tərəfimizdən əvvəllər təkliflər verilmişdir [19, c. 56, 20, c. 49]. Biz, habelə araşdırılan məsələnin həlli ilə bağlı digər təklif və yanaşmaların mümkün olduğunu da inkar etmirik. Lakin düşünürük ki, onlar Azərbaycan Respublikasında həyata keçirilən cinayət-hüquq və cəza-icra siyasətlərinə, cinayət və cəzaların icrası qanunvericiliklərinin tələb və prinsiplərinə, habelə dövlətin müvafiq dövrdəki maliyyə imkanlarına uyğun olmalı və qısa zamanda həyata keçirilməlidir.

Sonluqda qeyd olunanlarla yanaşı, təhlili aparılan, habelə dövlət başçısının da diqqət yetirdiyi vacib problemin tam həllinə kimi, cəzasının çəkilməsi məntəqə tipli çəzaçəkmə müəssisələrində təyin edilmiş, əmək qabiliyyətli məhkumların Azərbaycan Respublikasının işğaldan azad edilmiş ərazilərinə "Böyük Qayıdışa dair Dövlət Proqramı"nın icrasına, yəni ölkənin Qarabağ və Şərqi Zəngəzur iqtisadi rayonlarında aparılan bərpa və quruculuq işlərinə cəlb edilməsi məsələsinin də nəzərdən keçirilməsi məqsədəuyğun olardı.

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INSTITUTIONAL TRANSFORMATION AND COMPLIANCE WITH EUROPEAN UNION REQUIREMENTS: ALBANIA'S PATHWAY TO EU ACCESSION

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Abstract

The purpose of this study is to analyse Albania's institutional transformation in the fields of the judiciary, anti-corruption governance, and fundamental rights within the framework of European Union accession and compliance with European Union requirements under the Fundamentals cluster. The methodology is based on a qualitative and analytical research design combining document analysis, comparative institutional analysis, and theoretical interpretation. The study draws upon official European Commission reports, national strategies, legislative acts, institutional performance reports, and academic literature on Europeanisation, institutional change, and rule of law governance. The results demonstrate that Albania has achieved substantial progress in judicial reform, anti-corruption mechanisms, and the protection of fundamental rights, particularly through the consolidation of judicial governance institutions, the strengthening of integrity systems, and the approximation of legislation with European Union standards in data protection, media freedom, equality, and children's rights. The conclusions indicate that, although formal legal and institutional alignment is highly advanced, effective implementation remains uneven due to administrative capacity constraints, coordination challenges, and inconsistent enforcement. The study recommends strengthening operational capacities, improving inter-institutional cooperation, investing in professional development, and enhancing domestic ownership to ensure the long-term sustainability of reforms. Additional data from European Commission assessments and national monitoring indicators show reform progress levels reaching 72 per cent in justice reform consolidation, 68 per cent in judicial efficiency, 86 per cent in quality of justice, and 87.5 per cent in implementation of the National Cross-Sectoral Anti-Corruption Strategy for 2024.

Keywords: European Union conditionality; rule of law; judicial reform; anti-corruption governance; fundamental rights; Albania.

Introduction

The rule of law constitutes one of the foundational principles of the European Union and represents a central condition for accession for all candidate countries. Within the current enlargement methodology, the Fundamentals cluster occupies a pivotal position, placing the judiciary, anti-corruption policies, and the protection of fundamental rights at the core of the accession process. Progress in these areas is not assessed solely through legislative approximation with the acquis of the European Union, but increasingly through the capacity of national institutions to implement reforms effectively, ensure accountability, and deliver measurable and sustainable results. For candidate countries, compliance with European Union requirements in the field of the rule of law therefore involves a profound transformation of governance structures, administrative practices, and institutional culture.

In this context, Albania represents one of the most significant examples of institutional transformation in the Western Balkans. Since obtaining candidate status and opening accession negotiations, the country has undertaken an extensive programme of constitutional, legislative, and institutional reforms designed to strengthen judicial independence, reinforce anti-corruption mechanisms, and enhance the protection of fundamental rights. The comprehensive justice reform initiated in 2016, including the extraordinary re-evaluation process known as vetting, has fundamentally reconfigured the judicial and prosecutorial system. At the same time, national strategies and legislative reforms have expanded the institutional architecture responsible for preventing corruption, safeguarding media freedom, protecting personal data, promoting equality, and advancing the rights of children and minorities.

These reforms take place within a broader framework of Europeanisation, in which domestic institutions adapt to external norms, standards, and monitoring mechanisms established by the European Union and assessed by the European Commission. The enlargement process has transformed European Union conditionality into a powerful governance instrument, linking progress in accession negotiations to the achievement of specific benchmarks related to institutional independence, integrity, efficiency, and accountability. Consequently, Albania's reform trajectory offers an important case for examining how external incentives interact with domestic institutional capacities and constraints in shaping long-term governance change.

The significance of this study lies in the fact that, despite substantial legislative and institutional progress, the sustainability and effectiveness of reforms remain uneven. While formal alignment with European Union requirements is highly advanced, implementation continues to be affected by administrative limitations, fragmented coordination, and disparities in enforcement across institutions. This creates an important analytical question regarding the extent to which externally driven reforms have become fully embedded

within domestic governance structures and whether institutional transformation has moved beyond formal compliance toward substantive and durable consolidation.

The purpose of this article is to analyse Albania's institutional transformation in the fields of the judiciary, anti-corruption governance, and fundamental rights within the framework of European Union conditionality and accession requirements. The study seeks to assess the degree to which reforms have strengthened the rule of law, to identify the principal factors affecting implementation, and to evaluate the relationship between external European Union incentives and domestic institutional ownership. In doing so, the research addresses how legislative approximation, institutional restructuring, and performance-based governance interact in the broader process of state modernisation.

The study is guided by three central research questions. First, how has Albania's judicial system evolved from extraordinary reform interventions toward a post-vetting phase of institutional consolidation? Second, to what extent have anti-corruption and integrity mechanisms developed into an effective and coordinated system of accountability? Third, how does European Union conditionality influence the depth, sustainability, and effectiveness of institutional transformation across the rule of law and fundamental rights domains?

By addressing these questions, this article contributes to the academic literature on Europeanisation, institutional change, and enlargement policy. It provides an integrated analysis of Albania's reform trajectory at a critical stage of the accession process and offers broader insights into the dynamics of rule of law consolidation in candidate countries. The study argues that Albania's experience reflects a hybrid model of institutional transformation in which formal convergence with European Union standards has advanced considerably, while the long-term effectiveness of reforms depends on strengthening administrative capacity, improving inter-institutional coordination, and deepening domestic ownership of the reform agenda.

Methodology

This study adopts a qualitative, analytical, and interpretative research design aimed at examining Albania's institutional transformation in the fields of judicial governance, anti-corruption frameworks, and fundamental rights within the broader context of European Union accession and compliance with European Union requirements under the Fundamentals cluster.

The methodological approach is based on structured documentary analysis and institutional assessment. The study relies on primary and secondary sources, including official reports and monitoring documents issued by the European Commission, national legislative acts and strategic policy documents of the Republic of Albania, institutional performance reports from relevant governance bodies, as well as international evaluation frameworks such as GRECO assessments and EU rule of law monitoring instruments.

The analysis focuses on three main thematic pillars: (i) judicial governance and post-vetting institutional consolidation, (ii) anti-corruption and integrity systems, and (iii) fundamental rights protection, including media freedom, data protection, equality, and minority rights. Each pillar is examined through institutional indicators related to legal alignment, implementation capacity, governance effectiveness, and compliance with European Union standards.

Where previously established theoretical frameworks are applied, including Europeanisation theory, EU conditionality, and institutional change models, the study does not modify these frameworks but instead uses them as analytical lenses to interpret empirical developments. The methodology ensures comparability across sectors while maintaining a consistent focus on institutional transformation processes.

The approach prioritises reproducibility through transparent use of publicly available policy documents and official assessments, enabling a systematic evaluation of reform progress and institutional performance over time.

Background – Judicial Governance and Rule of Law Consolidation

The empirical evidence on Albania's judicial transformation indicates a reform trajectory that is structurally anchored in European Union conditionality and progressively embedded within domestic governance architecture. The latest European Commission assessments underline that Albania has continued advancing in the consolidation of rule of law institutions, particularly through the implementation of comprehensive justice reform measures and the strengthening of key accountability mechanisms (European Commission, 2025a). This dynamic reflects not merely a process of legal harmonisation, but a deeper institutional reconfiguration in which judicial governance is increasingly measured through performance-based and EU-aligned benchmarks (European Commission, 2025b).

A central component of this transformation is the operationalisation of the Intersectoral Justice Strategy 2024–2030, which establishes a structured framework for evaluating judicial performance across indicators such as independence, efficiency, quality of adjudication, and access to justice. In the 2025 Rule of Law assessment, the European Commission explicitly notes that Albania has made "continued progress in implementing justice reform, including institutional strengthening and the completion of key phases of vetting" (European Commission, 2025a). This indicates that reform is no longer limited to normative alignment, but is increasingly oriented toward measurable institutional outputs, thereby reinforcing a shift toward results-based governance.

Within this framework, judicial governance bodies such as the High Judicial Council and the High Prosecutorial Council have assumed a structurally pivotal role in consolidating post-vetting institutional stability. Their emergence as self-governing institutions reflects a gradual transition from externally driven reform oversight toward domestically institutionalised accountability structures. According to the European Commission (2025b), the strengthening of these bodies has been instrumental in enhancing merit-based recruitment and reinforcing transparency in judicial career management. However, the same assessment highlights that administrative capacity constraints and vulnerability to

informal influence remain key challenges, thereby indicating that institutional autonomy is still in a consolidation phase rather than fully achieved (European Commission, 2025b).

The transitional vetting process continues to represent a foundational mechanism in redefining judicial legitimacy and restoring public trust. The European Commission (2025a) confirms that the completion of key stages of vetting has contributed significantly to improving integrity standards and removing individuals failing to meet judicial criteria. From an institutional perspective, this process has established a normative baseline that now informs permanent mechanisms of accountability, including disciplinary oversight and ethical evaluation procedures. Nevertheless, the Commission also emphasises that the full integration of vetting-derived standards into ordinary judicial governance structures remains incomplete, particularly within inspection and oversight institutions (European Commission, 2025a).

Parallel to governance reforms, improvements in judicial efficiency constitute a second major dimension of transformation. The introduction of digital case management systems, backlog reduction strategies, and efficiency roadmaps reflects a gradual institutional shift toward performance-oriented administration. The 2025 Enlargement Report notes progress in judicial infrastructure and the implementation of electronic case management tools as part of broader modernisation efforts (European Commission, 2025a). However, persistent structural inefficiencies, including staffing shortages and delays in judicial appointments, continue to generate uneven performance across courts, thereby limiting the overall coherence of the system (European Commission, 2025b).

Capacity-building efforts, particularly through the School of Magistrates, further reinforce the institutionalisation of professional standards within the judiciary. The European Commission (2025b) highlights the expansion of continuous training programmes, especially in areas related to fundamental rights and EU legal standards, as a key driver of long-term institutional sustainability. This reflects a broader attempt to align human capital development with acquis requirements, thereby linking judicial professionalism directly to the EU integration agenda. Nonetheless, the effectiveness of these reforms remains contingent upon institutional retention capacity, as high turnover rates continue to undermine long-term stability within the judiciary (European Commission, 2025a).

At the systemic level, EU conditionality continues to function as both an external evaluative mechanism and an internal policy driver. The 2025 Enlargement Package confirms that Albania's progress in opening negotiation chapters and advancing rule of law reforms has been closely linked to structured EU monitoring and benchmarking processes (European Commission, 2025b). This dual role of conditionality reinforces reform momentum while simultaneously raising questions regarding the depth of domestic ownership in sustaining institutional change beyond accession incentives.

Overall, the empirical findings suggest that Albania has achieved a significant degree of formal institutional transformation within its judiciary, particularly in terms of governance restructuring, integrity enhancement, and procedural modernisation. However, the persistence of administrative inefficiencies, capacity limitations, and uneven implementation indicates that the reform process remains incomplete. As the European Commission (2025a) concludes, while progress is evident across key rule of law indicators, consolidation requires sustained institutional commitment and deeper embedding of reforms within everyday judicial practice.

EU Conditionality and Rule of Law Institutionalization

The empirical trajectory of Albania's judicial reform cannot be fully understood outside the theoretical architecture of European Union conditionality and its implications for rule of law institutionalisation in enlargement contexts. From a theoretical standpoint, the observed reforms reflect the classic logic of *external incentives-driven transformation*, where compliance with EU acquis and progress benchmarks functions as the primary mechanism shaping domestic institutional change (Schimmelfennig & Sedelmeier, 2005; European Commission, 2025).

In this framework, the strengthening of judicial governance bodies such as the High Judicial Council and the High Prosecutorial Council can be interpreted as a shift from *external enforcement* toward *embedded self-regulation*. The empirical evidence showing increased reliance on merit-based appointments and structured accountability mechanisms suggests partial internalisation of EU rule of law norms. However, according to conditionality theory, such internalisation remains contingent and reversible as long as it is primarily sustained by accession incentives rather than deep normative convergence (Börzel & Risse, 2012).

The completion of the vetting process represents a critical institutional "reset moment" that aligns with what the literature defines as *critical juncture-driven institutional transformation*. Vetting has not only removed actors deemed incompatible with integrity standards but has also established a new normative baseline for judicial accountability. Yet, the persistence of implementation gaps in post-vetting oversight confirms a well-documented theoretical limitation of EU-driven reforms: formal institutional redesign does not automatically translate into stable behavioural change within bureaucratic systems (Levitsky & Murillo, 2009; European Commission, 2024).

From a governance perspective, the increasing role of performance indicators within the Intersectoral Justice Strategy reflects the diffusion of *New Public Management (NPM)* principles into the judicial sector. Efficiency benchmarks, digitalisation processes, and backlog reduction mechanisms indicate a shift toward output-oriented governance. However, as comparative institutional theory suggests, the transplantation of performance-based models into rule of law institutions often produces uneven outcomes when administrative capacity and interoperability remain constrained (Pollitt & Bouckaert, 2017).

The empirical observation that reform consolidation reaches 72%, efficiency 68%, and quality 86% further reinforces a key theoretical insight: institutional Europeanisation is inherently asymmetrical. In line with multi-level governance theory, different dimensions of reform evolve at different speeds due to variations in administrative capacity, political salience, and institutional resistance (Marks & Hooghe, 2004; European Commission, 2025). This explains why improvements in formal governance structures coexist with persistent operational bottlenecks.

Furthermore, the continued reliance on EU progress reports and monitoring mechanisms confirms the validity of *external governance theory*, which posits that EU influence is most effective in policy areas characterised by high legalisation and clear benchmarks. However, in judiciary-related reforms, where informal practices and professional norms play a decisive role, the effectiveness of conditionality becomes more dependent on domestic ownership and institutional resilience (Lavenex & Schimmelfennig, 2011).

In synthesis, the Albanian case empirically confirms a hybrid theoretical model of institutional transformation. On one hand, EU conditionality operates as a powerful structuring force that drives formal convergence with EU standards. On the other hand, the persistence of implementation gaps, capacity constraints, and uneven reform outcomes supports the argument that rule of law consolidation is a long-term process of *incremental institutional layering* rather than linear convergence.

This theoretical framing provides the analytical bridge to the subsequent empirical domains, particularly anti-corruption governance, media freedom, and equality institutions, where similar patterns of conditionality-driven reform and partial institutionalisation are expected to emerge.

Institutional Transformation Beyond the Judiciary: Anti-Corruption Governance, Fundamental Rights, and State Capacity Expansion

The second empirical layer of Albania's rule of law transformation extends beyond the judiciary and is primarily structured around anti-corruption governance, integrity systems, media freedom, data protection, and equality institutions. In theoretical terms, this domain reflects the widening scope of EU conditionality from judicial independence benchmarks toward a more integrated conception of rule of law governance, where institutional performance is assessed through interdependent administrative, regulatory, and accountability systems (European Commission, *Enlargement Package*, 2024; European Commission, *Rule of Law Report*, 2025; Börzel & van Hüllen, 2014).

A central empirical development concerns the consolidation of the national anti-corruption framework under the Strategy Against Corruption 2024–2030 (Council of Ministers Decision No. 859, 26.12.2024). The transition from fragmented interventions toward a consolidated governance architecture is evidenced by a reported implementation rate of 87.5% for 2024 and a mid-year execution rate of 71.3% for 2025, covering prevention, repression, and awareness pillars (Ministry of State for Public Administration and Anti-Corruption, 2025). The institutionalisation of monitoring mechanisms, including the 2024 Compliance Report approved on 10 June 2025 and the 2025 mid-year compliance assessment, further indicates the emergence of performance-based anti-corruption governance. From a theoretical perspective, this reflects a shift toward "whole-of-government" integrity systems, in which anti-corruption policy becomes a horizontal governance function embedded across state structures rather than a standalone policy field (OECD, *Public Integrity Handbook*, 2020; European Commission, 2025).

At the institutional level, the strengthening of integrity oversight bodies, particularly the High Inspectorate for the Declaration and Audit of Assets and Conflict of Interest (ILDKPKI), illustrates a gradual deepening of administrative control over public integrity systems. Following the entry into force of Law No. 124/2024 on Personal Data Protection, ILDKPKI has adopted a full set of secondary legislation and operational methodologies, including risk-based verification tools and sanctioning frameworks (Commissioner for Information and Data Protection, 2025). The gradual incorporation of vetting-derived standards into ordinary asset declaration verification procedures signals a post-transitional phase of accountability institutionalisation. However, empirical evidence shows that full methodological consolidation remains incomplete, particularly in relation to inter-agency data exchange, risk profiling, and proactive detection of concealed assets through third-party ownership structures and lifestyle analysis (ILDKPKI Annual Activity Report, 2025). This aligns with comparative institutionalist arguments that integrity reforms in hybrid regimes evolve through incremental layering rather than systemic rupture (Levitsky & Murillo, 2009; Helmke & Levitsky, 2004).

Parallel developments in enforcement capacity demonstrate increasing institutional specialisation within anti-corruption governance. The expansion of digital access to state databases and the operationalisation of investigative systems such as CAMS reflect a broader shift toward data-driven enforcement governance (World Bank, *Governance and Institutions Framework*, 2023). Training programmes for prosecutors and judicial police officers have further strengthened technical capacities in financial crime investigation and asset recovery. Nevertheless, empirical governance literature highlights persistent asymmetries in analytical capacity and human capital as key constraints on enforcement effectiveness in transitional administrations (Pollitt & Bouckaert, 2017).

Albania's alignment with GRECO recommendations further illustrates the role of external accountability regimes in shaping domestic institutional reform. The Second Compliance Report under the Fifth Evaluation Round, completed in March 2025, confirms partial implementation, with several recommendations still in progress, particularly regarding executive integrity and law enforcement governance (GRECO, *Second Compliance Report – Albania*, 2025). This partial compliance trajectory supports the theoretical proposition that anti-corruption reforms exhibit non-linear convergence patterns, especially where institutional change requires shifts in organisational culture and informal norms rather than purely legal alignment (Mungiu-Pippidi, 2015; Heywood, 2018).

A further dimension of transformation is observed in data protection and digital governance. The adoption of Law No. 124/2024 and the issuance of ten implementing acts by the Commissioner for Information and Data Protection in 2025 represent rapid alignment with the EU acquis, particularly the GDPR framework and related sectoral directives. These secondary acts cover domains such as education, health data, video surveillance, direct marketing, and administrative sanctions methodologies (IDP Albania, 2025). This reflects a classic pattern of regulatory Europeanisation, where legislative convergence progresses faster than enforcement capacity and institutional learning (Lavenex & Schimmelfennig, 2011; European Commission, 2025). While the normative framework is largely harmonised, implementation effectiveness depends on supervisory independence, institutional resourcing, and technical expertise within regulatory bodies.

In the field of media freedom and freedom of expression, Albania's reform trajectory reflects a dual dynamic of legal approximation and institutional experimentation. The advancement of alignment with the European Media Freedom Act (EMFA) and Audiovisual Media Services Directive (AVMSD), combined with the outputs of the Media Dialogue Platform submitted to Parliament in October 2025, demonstrates formal convergence with EU regulatory standards (European Commission, 2025). At the same time, institutional innovations such as coordinated journalist protection mechanisms across police, prosecution, and regulatory agencies reflect an emerging multi-agency governance model for media safety. However, media systems theory suggests that legal alignment alone does not guarantee structural independence, particularly in contexts characterised by media concentration and labour precarity (Hallin & Mancini, 2004; Picard, 2015). The long-term effectiveness of these reforms will therefore depend on enforcement consistency and institutional autonomy.

The equality and non-discrimination framework further illustrates the expansion of rights-based governance. The adoption of the Gender Equality Law (Law adopted November 2025) and ongoing alignment with EU directives on equality bodies and anti-discrimination reflect a mainstreaming approach to fundamental rights within public policy (European Commission, 2024; FRA, *Fundamental Rights Report*, 2025). This institutionalisation of equality norms across policy sectors aligns with the EU's "rights mainstreaming" paradigm, in which equality is operationalised as a cross-cutting governance principle rather than a standalone legal domain. However, implementation remains dependent on administrative capacity at both central and local levels, particularly regarding victim support services and coordination mechanisms within decentralised governance structures.

Finally, reforms in property rights administration and cadastral governance illustrate the intersection between digital transformation and rule of law consolidation. The high level of digitisation of cadastral records (over 75% of files and reference documents by 2025) and the expansion of integrated property registration systems via e-government platforms and blockchain-based verification mechanisms reflect a structural shift toward procedural transparency and administrative rationalisation (World Bank, *Digital Government Review*, 2024). The completion of 15 cadastral zones and ongoing implementation of over 100 additional zones under the First Registration Programme demonstrate continued institutional capacity expansion (State Cadastre Agency, 2025). Nevertheless, the persistence of backlog cases and unresolved property claims indicates that digital transformation, while necessary, is insufficient to fully resolve entrenched historical institutional fragmentation.

Overall, the empirical evidence from this second domain confirms a consistent analytical pattern: Albania's rule of law transformation is characterised by strong formal alignment with EU standards, combined with uneven and partial implementation outcomes. Theoretically, this supports a hybrid Europeanisation model in which external conditionality, institutional layering, and administrative capacity constraints jointly shape reform trajectories (Schimmelfennig & Sedelmeier, 2005; Börzel, 2021). Institutional transformation is therefore best understood not as linear convergence but as a prolonged process of adaptive governance under multi-level European integration pressures.

Judicial Quality, Efficiency, and Institutional Consolidation in the Post-Vetting Phase

The consolidation of Albania's judicial system in the post-vetting phase reflects a transition from extraordinary integrity-based reforms toward the strengthening of institutional capacity, efficiency, and service delivery, in line with the Intersectoral Justice Strategy 2024–2030 and EU accession requirements on judicial independence and accountability (Ministry of Justice, 2025; European Commission, 2025).

A key feature of this phase is the overall advancement of justice reform implementation, which has reached a consolidation level of 72%, alongside progress in institutional independence, impartiality, and accountability at 60%. Judicial efficiency has improved to 68%, while the quality of justice represents the strongest performance area at 86%. Access to justice has also shown steady improvement, reaching 74% (Ministry of Justice, 2025). These indicators demonstrate gradual strengthening of system performance across core governance dimensions.

Institutional consolidation is closely linked to the completion of the vetting process and the continuation of post-vetting integrity mechanisms under domestic judicial bodies, including the High Judicial Council (KLGJ), the High Prosecutorial Council (KLP), and the High Inspector of Justice (ILD). These institutions continue to enforce integrity through asset verification, ethical oversight, and merit-based career progression, while also initiating steps to incorporate vetting-level standards into internal inspection systems (High Inspector of Justice, 2025; EU4Justice, 2025). Coordination with international partners such as the EU Delegation and technical assistance programs further supports this transition phase (European Commission, 2025).

A central efficiency indicator is the reduction of case backlogs, with courts achieving approximately two-thirds of their annual planning targets. This reflects

improvements in judicial throughput supported by workforce redistribution and procedural adjustments (Ministry of Justice, 2025). In parallel, the High Judicial Council (KLGJ) and the High Prosecutorial Council (KLP) have developed structured workforce planning frameworks based on caseload analysis to better align staffing levels with system demands (KLGJ, 2025; KLP, 2025).

Institutional governance has also been strengthened through regulatory reforms related to judicial appointments, career development, and ethical standards. The adoption of updated rules for the appointment of court presidents and prosecutorial ethics frameworks reflects a shift toward a more merit-based and rule-governed judicial career system (KLGJ, 2025; KLP, 2025). These reforms aim to reduce discretionary decision-making and reinforce institutional professionalism.

Digital transformation constitutes another key pillar of judicial modernization. The development of the Integrated Case Management Information System (ICMIS) is intended to unify fragmented judicial IT systems and standardize electronic processes, including e-notification services across all courts (European Commission e-Justice, 2024; World Bank, 2023). However, limitations in system ownership and interoperability of existing platforms continue to constrain full digital integration.

Despite these improvements, structural challenges persist, particularly in relation to staffing shortages, uneven administrative capacity, and persistent caseload pressures across jurisdictions. Although legal support units and additional magistrate positions have been introduced, sustainable improvements depend on long-term institutional adaptation and continued resource allocation (CEPEJ, 2024; Ministry of Justice, 2025).

Property rights administration remains a significant area affecting judicial workload and efficiency. More than 20,000 property-related decisions have been resolved, alongside ongoing compensation processes. However, unresolved cases and financial backlogs continue to reflect the complexity of property governance in post-socialist legal systems and its impact on judicial capacity (World Bank, 2024; Ministry of Justice, 2025).

Overall, Albania's judicial system is entering a post-exceptional phase of reform characterized by institutional consolidation rather than structural redesign. The main challenge lies in ensuring the sustainability of reforms, improving administrative efficiency, and strengthening coordination across justice institutions (Mahoney & Thelen, 2010; European Commission, 2025).

Integrity, Anti-Corruption Frameworks, and Institutional Accountability

The strengthening of Albania's integrity and anti-corruption framework is increasingly characterized by a transition from formal compliance toward more operational enforcement, digitalisation of oversight mechanisms, and gradual alignment with EU standards in asset declaration, conflict of interest prevention, and systemic anti-corruption coordination (European Commission, 2025; GRECO, 2025).

A central institution in this framework is the High Inspectorate for the Declaration and Audit of Assets and Conflicts of Interest (ILDKPKI), which has continued to consolidate its role in asset declaration verification and transparency enforcement. In the post-legal reform phase, ILDKPKI has expanded the operational use of its public disclosure portal and strengthened procedures for access to asset declaration registers, contributing to improved transparency and public oversight (ILDKPKI, 2025). At the same time, the institution has developed a draft Operational Development Action Plan for 2026–2027, focusing on institutional integrity, digital transformation of verification systems, enhanced inter-institutional data exchange, and improved effectiveness of asset control mechanisms (ILDKPKI, 2025).

Cooperation with EU-funded technical assistance programs, particularly EU4GG, has further supported ILDKPKI's institutional development. In this context, the institution has actively engaged in reviewing methodological assessments of its operational procedures, providing detailed technical comments on preliminary evaluation reports and requesting clarifications on identified methodological inconsistencies before finalisation (EU4GG, 2025). This reflects a broader effort to align domestic verification standards with EU best practices in asset disclosure and integrity auditing.

From a structural perspective, however, ILDKPKI continues to face significant capacity-related constraints. Key challenges include the need for further standardisation of verification methodologies, particularly in relation to the detection of hidden assets, third-party ownership structures, and lifestyle-based financial inconsistencies (GRECO, 2025). In addition, effective implementation requires stronger inter-agency cooperation with tax authorities, financial intelligence units, and prosecutorial bodies, as well as improved access to integrated administrative databases (GRECO, 2025; ILDKPKI, 2025). These gaps highlight the ongoing transition from formal verification systems toward more proactive and intelligence-driven asset control mechanisms.

Within the broader anti-corruption governance framework, the implementation of the National Cross-Sectoral Anti-Corruption Strategy 2024–2030 (SNKK) represents the main policy instrument for coordination and monitoring of anti-corruption reforms. The strategy has recorded a relatively high overall implementation rate of 87.5% for 2024, with particularly strong performance in prevention and enforcement pillars, while awareness-raising components remain comparatively weaker (SNKK, 2025). The mid-2025 monitoring report indicates a moderate decline in implementation intensity to 71.3%, reflecting the transitional phase of operationalisation across institutions and the need for improved coordination mechanisms at sector level (SNKK, 2025).

Institutionalisation of SNKK implementation is supported through the development of monitoring manuals, focal point coordination structures, and periodic evaluation tools, with technical assistance provided by EU governance programs (SNKK, 2025; EU4GG, 2025). These instruments are intended to strengthen consistency in reporting, improve accountability, and enhance the capacity of institutions to translate strategic objectives into measurable outputs.

In parallel, the implementation of GRECO recommendations continues to serve as an external benchmark for assessing Albania's progress in integrity and anti-corruption reforms. The completion of the Fifth Evaluation Round compliance report in 2025 confirms partial progress, with several recommendations still pending full implementation (GRECO, 2025). Remaining gaps primarily relate to the strengthening of asset verification systems, improved enforcement of administrative investigations, and more consistent application of integrity standards across public administration and law enforcement bodies (GRECO, 2025).

Despite progress, GRECO underlines that the effectiveness of the anti-corruption framework depends on the consistent application of recommendations and the institutional capacity to ensure sustained enforcement over time (GRECO, 2025). This includes strengthening the independence and technical capacity of oversight institutions, improving coordination among enforcement bodies, and ensuring that administrative findings are systematically translated into judicial or prosecutorial action where necessary.

Overall, the integrity and anti-corruption system in Albania is evolving toward a more structured and coordinated model, combining national strategic planning (SNKK), international monitoring frameworks (GRECO), and institutional enforcement mechanisms (ILDKPKI). However, the system remains in a transitional phase, where the main challenge is not the existence of legal frameworks, but their effective operationalisation, inter-institutional coordination, and long-term sustainability of enforcement capacity (European Commission, 2025; GRECO, 2025).

Fundamental Rights: Media Freedom, Data Protection, Minorities, Children, and Equality

The advancement of fundamental rights protection in Albania is increasingly characterised by the consolidation of legal alignment with the EU acquis, combined with the gradual operationalisation of institutional mandates across key rights-based sectors. While significant legislative progress has been achieved, particularly in the areas of data protection, gender equality, and media regulation, the main challenge remains the effective implementation, inter-institutional coordination, and sustainable administrative capacity across rights institutions (European Commission, 2025).

In the area of **data protection**, the adoption of the revised legal framework and its implementing measures marks a decisive step toward full alignment with EU standards. Following the entry into force of Law No. 124/2024 on Personal Data Protection, the Commissioner for the Right to Information and Data Protection has completed the full set of ten implementing bylaws, covering key domains such as sector-specific safeguards (education and health), video surveillance, direct marketing, enforcement methodologies, and certification procedures. This regulatory package significantly strengthens the operational basis of the supervisory authority and introduces more structured compliance and sanctioning mechanisms. However, effective implementation remains contingent on adequate institutional capacity, particularly in terms of human resources, technical expertise, and inter-agency data governance systems, as highlighted in EU monitoring frameworks (European Commission, 2025).

Regarding **freedom of expression and media freedom**, institutional developments reflect a gradual alignment with the European Media Freedom Act (EMFA) and the Audiovisual Media Services Directive (AVMSD). The Audiovisual Media Authority (AMA), in cooperation with media stakeholders and international partners, has advanced regulatory approximation efforts, including consultations on media ownership transparency, regulatory independence, and media concentration. The establishment of structured dialogue platforms and thematic working groups has contributed to more inclusive policy formulation processes, while recommendations have been formally transmitted to the Parliament for consideration. In parallel, measures to enhance journalist safety have been reinforced through the designation of institutional contact points within the police and prosecution services, supported by training programmes and operational guidelines. Despite these developments, media governance continues to face structural challenges related to regulatory independence, market concentration, and the sustainability of journalistic safety mechanisms (European Commission, 2025).

In the field of **minority rights**, Albania has continued the implementation of the legal framework on national minorities, particularly through the operationalisation of self-identification procedures. The functioning of the relevant commission has enabled the formal recognition of self-declared minority affiliation cases, while administrative measures have been introduced to address discriminatory barriers in access to public services, including education-related benefits. At the institutional level, capacity-building efforts have been supported through training programmes targeting public administration staff on fundamental rights and anti-discrimination standards. Nevertheless, challenges persist in ensuring consistent implementation at local level, particularly regarding awareness, administrative uniformity, and data collection capacities for policy monitoring.

Concerning **children's rights**, progress is primarily linked to the strengthening of the institutional framework for child protection and the gradual expansion of community-based services. The ongoing development of a new Alternative Care Law and the implementation of the National Agenda for Children's Rights reflect a strategic shift toward deinstitutionalisation and family-based care models. The establishment and expansion of Needs Assessment and Referral Units (NARU) in municipalities represents a key step toward decentralised child protection systems. However, the effectiveness of these reforms remains dependent on sufficient budget allocation, inter-municipal capacity, and the consolidation of case management systems at local level, particularly in crisis response and specialised care provision.

In the area of **equality and non-discrimination**, legislative progress has been achieved through the adoption of the Gender Equality Law and the advance-

ment of alignment with key EU equality directives, including those on racial equality, gender-based violence, and accessibility standards. Institutional mechanisms for equality protection have been further strengthened through policy coordination and training activities targeting public administration structures. Nonetheless, the effectiveness of the equality framework continues to depend on enforcement capacity, availability of disaggregated data, and the operational effectiveness of equality bodies, particularly in ensuring access to remedies and protection mechanisms for vulnerable groups.

Overall, the fundamental rights system in Albania demonstrates a clear trajectory of legislative convergence with EU standards and gradual institutional strengthening across key rights domains. However, the system remains in a transitional implementation phase, where the primary constraint is not the absence of normative frameworks, but the uneven enforcement capacity, limited administrative resources, and the need for stronger coordination across institutions responsible for rights protection (European Commission, 2025).

Discussion

The analysis presented in this study demonstrates that Albania's institutional transformation in the area of rule of law is primarily driven by a structured process of EU conditionality, which has progressively shifted from a focus on formal legislative alignment toward more performance-based and implementation-oriented governance. Across the judiciary, anti-corruption architecture, and fundamental rights domains, reform dynamics reveal a consistent pattern of institutional consolidation under external Europeanisation pressures, combined with persistent internal capacity constraints that limit full operational effectiveness (European Commission, 2025).

A central finding of this research is that Albania's justice reform process reflects a transition from extraordinary, externally supported interventions—most notably the vetting process—toward a post-vetting phase characterised by institutional normalisation and system consolidation. Judicial governance bodies such as the High Judicial Council and High Prosecutorial Council have become the main anchors of this new institutional equilibrium. However, despite measurable progress in efficiency, quality, and access to justice, the system continues to face structural limitations related to staffing shortages, administrative capacity, and uneven case management performance. This confirms that institutional redesign has outpaced institutional absorption, producing a gap between formal structures and practical functionality (European Commission, 2025).

Within this broader trajectory, the anti-corruption and integrity framework illustrates a parallel process of institutional layering and gradual operationalisation. Institutions such as ILDKPKI, alongside the implementation of the National Anti-Corruption Strategy (SNKK) and GRECO recommendations, demonstrate a clear shift toward integrated integrity governance. The increasing use of digital tools, expanded asset declaration systems, and structured monitoring mechanisms reflects a move toward more intelligence-driven oversight. However, the persistence of methodological weaknesses, limited inter-agency coordination, and gaps in enforcement capacity indicate that anti-corruption governance remains in a transitional phase between formal compliance and effective deterrence (GRECO, 2025; SNKK, 2025).

When interpreted through the lens of EU conditionality theory, these developments confirm that Albania's institutional reforms are largely shaped by external incentives and benchmarking mechanisms. The high degree of legislative approximation across sectors such as data protection, media regulation, and equality demonstrates strong normative convergence with the EU acquis. Nevertheless, consistent with established literature on Europeanisation, implementation outcomes remain uneven, particularly in areas requiring administrative discretion, professional autonomy, and inter-institutional coordination. This supports the argument that conditionality is highly effective in producing formal institutional change but less effective in ensuring deep behavioural transformation within domestic bureaucracies (Schimmelfennig & Sedelmeier, 2005; Börzel & Risse, 2012).

A key cross-cutting finding is the persistent gap between institutional formalisation and administrative capacity. Across all examined domains—judiciary, anti-corruption, and fundamental rights—reform success is strongest in legislative alignment and institutional restructuring, while weaker in enforcement consistency, operational coordination, and long-term sustainability. This suggests that Albania's rule of law system is evolving through a process of incremental institutional layering rather than linear convergence, where new institutions and frameworks are continuously added to existing structures without fully resolving legacy inefficiencies (Levitsky & Murillo, 2009).

The fundamental rights domain further reinforces this pattern. While legal alignment with EU standards in areas such as data protection, media freedom, gender equality, and minority rights is advanced, implementation remains uneven due to limited institutional capacity and fragmented enforcement mechanisms. Media governance continues to face challenges related to regulatory independence and market concentration, while equality and child protection systems remain dependent on local-level administrative effectiveness. These findings indicate that rights-based governance in Albania is increasingly formalised but not yet fully institutionalised in practice.

From a broader governance perspective, the Albanian case illustrates the emergence of a hybrid model of rule of law transformation, where EU-driven conditionality interacts with domestic institutional constraints to produce partial but sustained reform outcomes. This hybridisation is characterised by strong external steering, gradual internal adaptation, and persistent implementation deficits. As a result, institutional transformation should not be understood as a completed transition toward EU standards, but rather as an ongoing process of adaptive convergence shaped by both incentives and capacity limitations.

In conclusion, the findings confirm that Albania's rule of law reforms are structurally anchored in EU integration logic and have achieved significant progress in formal institutional alignment. However, the long-

term effectiveness of these reforms depends on the ability of domestic institutions to move beyond compliance-oriented implementation toward sustained operational capacity, inter-institutional coordination, and administrative resilience. The central challenge remains not the design of institutions, but their effective functionality within a complex and resource-constrained governance environment.

Conclusion

This study aimed at analysing Albania's institutional transformation in the areas of judiciary, anti-corruption governance, and fundamental rights within the broader framework of EU conditionality and rule of law consolidation. By combining empirical evidence from EU monitoring reports, national strategies, and institutional performance data, the study provides a comprehensive understanding of how Albania's governance system is progressively reshaped through Europeanisation processes.

1. In addressing RQ1, the study finds that Albania's judicial reform represents a structured transition from externally driven intervention—particularly the vetting process—toward a post-vetting phase of institutional consolidation. Judicial governance bodies such as the High Judicial Council and the High Prosecutorial Council have become central actors in ensuring continuity of reforms, reinforcing merit-based career systems and institutional accountability. However, despite improvements in efficiency, quality, and access to justice, the judiciary remains constrained by administrative capacity gaps, uneven workload distribution, and persistent structural inefficiencies. This indicates that institutional redesign has advanced faster than full operational consolidation.

2. In addressing RQ2, the research demonstrates that Albania's anti-corruption framework has evolved from fragmented policy interventions toward a more structured and coordinated integrity system. Institutions such as ILDKPKI, alongside the implementation of the SNKK 2024–2030 strategy and GRECO recommendations, reflect a shift toward performance-based and digitally supported governance. Nevertheless, the persistence of methodological limitations in asset verification, weak inter-agency coordination, and uneven enforcement capacity highlights that anti-corruption reform remains in a transitional stage between formal compliance and effective deterrence.

3. In addressing RQ3, the findings confirm that EU conditionality remains the dominant external driver of institutional transformation. Across all sectors, legislative alignment with the EU acquis is highly advanced, particularly in data protection, media regulation, equality, and justice governance. However, the effectiveness of conditionality is constrained by implementation gaps, administrative fragmentation, and limited institutional resources. This supports the conclusion that Europeanisation in Albania operates primarily as a formal convergence mechanism, while substantive convergence remains incomplete and uneven.

4. The study further finds that Albania's rule of law transformation is characterised by a hybrid model of institutional change, where external EU incentives interact with domestic governance constraints. Reform progress is most visible in legal harmonisation and institutional restructuring, while weaker performance is evident in enforcement consistency and inter-institutional coordination. This confirms that institutional change follows a path of incremental layering rather than linear transformation.

5. The analysis of fundamental rights demonstrates significant progress in aligning national legislation with EU standards across media freedom, data protection, minority rights, children's rights, and equality policies. However, implementation remains uneven due to limited administrative capacity, regulatory independence challenges, and insufficient local-level enforcement mechanisms. As a result, rights protection is increasingly formalised in legal terms but not yet fully embedded in institutional practice.

6. The study suggests that Albania's ongoing transformation reflects a broader pattern of "conditional governance", where EU integration functions simultaneously as a legal harmonisation process and a long-term institutional restructuring mechanism. While this has produced substantial reforms, it has also created dependency on external benchmarks, raising questions about the depth of domestic ownership and long-term sustainability.

7. The empirical evidence across sectors shows that reform outcomes are uneven: strongest in legislative alignment and institutional design, moderate in efficiency and governance consolidation, and weakest in enforcement capacity and coordination. This confirms that the key challenge is no longer the absence of reform frameworks, but their effective implementation within a constrained administrative environment.

8. In conclusion, the study demonstrates that Albania's path toward EU accession is fundamentally shaped by a tension between formal convergence and practical institutional capacity. While significant progress has been achieved in building the legal and institutional foundations of the rule of law, the sustainability of reforms will depend on strengthening administrative capacity, ensuring consistent enforcement, and deepening domestic ownership of EU-driven reforms. The Albanian case thus illustrates that Europeanisation is not a linear process of convergence, but a complex and uneven trajectory of institutional adaptation under external conditionality pressures.

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Conflict of Interests

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MATHEMATICAL SCIENCES

SEASONALITY AND TREND IN SALES FORECASTING

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Abstract

Accurate monthly sales forecasting is a critical challenge for retail businesses worldwide, yet most organisations still rely on manual spreadsheet methods. This study presents the development of a unique forecasting model combining time series decomposition, comprehensive feature engineering, and gradient boosting machine learning. The model was developed and validated on real operational monthly sales data from a Kazakhstani retail business — a market that has received virtually no attention in the academic forecasting literature. A two-phase methodology is adopted: first, Pearson and Spearman correlation tests mathematically characterise the temporal structure of the data; second, a feature engineering framework combining sales history lags, rolling statistics, cyclic calendar encoding, price and promotional variables, inventory features, and locally specific indicators (including Ramadan) is built and evaluated on a held-out test set. LightGBM achieves the strongest performance, explaining 81% of total sales variance ($R^2 = 0.81$, RMSE = 1,996), substantially outperforming all classical approaches. Feature importance analysis reveals that incoming stock volume, product category, and selling price are more predictive than purely temporal features. A key design principle of the model is its adaptability: the feature set is designed to be extended for any country or region by incorporating locally relevant calendar events, holidays, and cultural demand drivers. The authors plan to release this model as a publicly available forecasting application suitable for businesses globally.

Keywords: Sales forecasting, time series, seasonality, trend, LightGBM, gradient boosting, SARIMAX, feature engineering, machine learning, correleation.

1. Introduction

Sales forecasting — estimating future product demand from historical data, seasonal patterns, trend, and business-context factors — is one of the most consequential analytical activities in retail management. Accurate forecasts drive inventory procurement, production scheduling, staffing, and marketing allocation. Errors in either direction are costly: overestimates generate excess stock and high holding costs; underestimates cause stockouts and lost revenue.

Despite substantial advances in forecasting methodology over the past century, many businesses in Kazakhstan continue to forecast demand manually using spreadsheets and moving averages. This gap is particularly significant because the Kazakhstani retail market combines rapid growth, diversifying consumer preferences, and seasonal variation tied to both global commercial cycles and locally specific patterns — above all the Islamic calendar, where Ramadan produces a sharp, category-specific demand spike that standard models cannot anticipate. Yet this market has received virtually no attention in the academic forecasting literature.

This paper addresses that gap. Using real monthly sales data from a Kazakhstani retail business — with all commercially sensitive identifiers withheld — it asks: which forecasting method best predicts monthly product sales, and why do some methods substantially outperform others? The answer turns out to depend critically on incorporating operational business variables, not merely time-series structure.

The paper makes two principal contributions. First, it applies a rigorous two-step mathematical analysis (Pearson and Spearman correlation) to characterise the temporal structure of the data before any modelling, providing an objective justification for subsequent choices. Second, it constructs a comprehensive feature engineering framework and demonstrates that combining it with LightGBM gradient boosting outperforms all classical and linear alternatives by a substantial margin.

2. Literature Review

The following tables summarise the key sources reviewed, organised by methodological category.

Table A.

Classical Statistical Models

Source	Goal	Methods / Approach	Application	Main Results	Limitations
Box & Jenkins (1970)	Develop a systematic forecasting methodology	ARIMA modeling, autocorrelation analysis, Box–Jenkins procedure	Economics, industrial production	Established the foundation of modern time series forecasting	Requires stationarity; limited handling of nonlinear seasonality
Holt (1957)	Improve short-term forecasting with trend and seasonality	Exponential smoothing, Holt and Holt–Winters models	Retail sales, inventory management	Effective for seasonal and trend data; simple to apply	Weak under sudden structural changes
Hyndman & Athanasopoulos (2018)	Provide a modern practical forecasting framework	ETS, SARIMA, seasonal decomposition	Business forecasting, retail demand	Confirmed effectiveness of statistical models for seasonal demand	Limited comparison with ML approaches

Table B.

Machine Learning Models

Source	Goal	Methods / Approach	Application	Main Results	Limitations
Breiman (2001)	Improve forecasting accuracy using ensembles	Random Forest, bagging, decision trees	Finance, demand forecasting	Models nonlinearities and factor interactions well	Lower interpretability
Chen & Guestrin (2016)	Develop a scalable boosting algorithm	XGBoost, gradient boosting over decision trees	Sales forecasting, tabular business data	High accuracy for structured and seasonal data	Requires careful hyperparameter tuning
Hochreiter & Schmidhuber (1997)	Solve long-term dependency problems in sequences	LSTM neural network architecture	Demand forecasting, energy forecasting	Captures long seasonal and temporal dependencies	Requires large datasets and computational resources

A third, hybrid phase has emerged combining decomposition-informed feature engineering with machine learning. Hyndman and Athanasopoulos [3] formalise ETS and STL decomposition as preprocessing steps. Zhou [10] and Hasan [11] demonstrate that LightGBM with decomposition-informed features outperforms both ARIMA and linear baselines on retail data. The present study develops a unique forecasting model within this hybrid paradigm, validated on Kazakhstani retail data and designed for global applicability through an extensible, country-adaptive feature set.

3. Mathematical Background

This section presents the mathematical tools used to analyse the data structure and motivate the modelling choices. Equations (1)–(7) are referenced throughout the paper.

3.1 Time series decomposition. Observed monthly sales are modelled as the superposition of systematic components. The additive decomposition is:

$$Y_t = T_t + S_t + E_t + \varepsilon_t \quad (1)$$

Y_t is the observed sales value at time t; T_t is the trend component (long-run direction); S_t is the seasonal component with cycle length $L = 12$ for monthly data; E_t captures external business factors (promotions, price changes, holidays); and $\varepsilon_t \sim N(0, \sigma^2)$ is independent noise.

When seasonal amplitude grows proportionally with the trend level, the multiplicative form is more appropriate:

$$Y_t = T_t \times S_t \times E_t \times \varepsilon_t \quad (2)$$

For the present dataset, the additive form (1) is appropriate because seasonal amplitude remains approximately constant across the observation period, as confirmed by visual inspection of the decomposed series.

3.2 Testing for linear trend. Before choosing a model, we test whether a statistically significant linear trend exists. The Pearson product-moment correlation coefficient between the time index and the sales series is:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2 \cdot \sum_{i=1}^{n}(y_i - \bar{y})^2}} \quad (3)$$

x_i is the time index of observation i, y_i is the corresponding sales value, and $\bar{x}$, $\bar{y}$ are their respective means. Significance under H_0: $\rho = 0$ is assessed via:

$$t = \frac{r_{xy}\sqrt{n-2}}{\sqrt{1 - r_{xy}^2}} \quad (4)$$

t follows a t-distribution with $n - 2$ degrees of freedom. For the aggregate monthly sales series ($n \approx 36$ observations), the computed value is $r_{xy} \approx 0.054$, yielding $t \approx 0.32$ — far below the critical value $t\_crit \approx 2.032$ at $\alpha = 0.05$. H_0 is not rejected: no statistically significant linear trend exists.

3.3 Detecting nonlinear seasonal structure. Because Pearson detects only linear associations, we additionally compute the Spearman rank correlation, which captures monotone nonlinear relationships:

$$r_s = 1 - \frac{6\sum_{i=1}^{n} d_i^2}{n(n^2 - 1)} \quad (5)$$

$d_i = \text{rank}(x_i) - \text{rank}(y_i)$. The average Spearman correlation across the product portfolio is $r_s \approx 0.68$, reaching $r_s \approx 0.90$ for strongly seasonal products such as ice cream and persimmon. The contrast between near-zero Pearson and strong Spearman directly justifies using nonlinear machine learning methods over linear regression or ARIMA.

3.4 SARIMAX model. The classical statistical benchmark used in this study is the SARIMAX(p,d,q)(P,D,Q)_S model, expressed in backshift operator notation as:

$$\Phi_P(B^S)\,\varphi_p(B)\,(1-B)^d(1-B^S)^D Y_t = \Theta_Q(B^S)\,\theta_q(B)\,\varepsilon_t + X_t\beta \quad (6)$$

B is the backshift operator ($BY_t = Y_{t-1}$); $\varphi p(B)$ and $\Phi P(B\text{^}S)$ are the non-seasonal and seasonal autoregressive polynomials; $\theta q(B)$ and $\Theta Q(B\text{^}S)$ are the moving average polynomials; $X_t\beta$ is the exogenous variable component (price, promotions). The specification used here is SARIMAX$(1,0,1)(1,1,0)_{12}$.

3.5 Gradient boosting. LightGBM and XGBoost both implement gradient boosting, which constructs an additive model by fitting weak learners sequentially to the negative gradient of the loss function:

$$F_M(x) = F_0(x) + \sum_{m=1}^{M} \eta\,\gamma_m\,h_m(x) \quad (7)$$

$F\_0(x)$ is the initial constant model; $h_m(x)$ is the m-th regression tree fitted to the pseudo-residuals; $\eta \in (0, 1]$ is the learning rate; and γ_m is the optimal leaf weight. To address the right-skewed sales distribution, a log-transformation is applied before training:

$$y^* = \log(1 + \text{sales\_qty}), \qquad \hat{y} = \exp(\hat{y}^*) - 1 \quad (8)$$

Equation (8) ensures predictions are always non-negative after back-transformation and reduces heteroscedasticity in the residuals.

4. Research Methodology

The study adopts a two-phase quantitative design. Phase one applies the correlation tests of equations (3)–(5) to the full dataset before any modelling, grounding all subsequent decisions in mathematical evidence. Phase two implements all five models on the same feature set and evaluates them on a held-out chronological test set comprising the most recent 20% of the observation period — a design that prevents data leakage and preserves the temporal ordering of observations.

Dataset. The data consist of operational monthly product-level sales records from a retail business in Kazakhstan, covering multiple product categories across a multi-year observation period. All commercially sensitive identifiers — business name, product names, and internal codes — are withheld. Each record contains: date variables (year, month, quarter), monthly sales quantity and revenue, retail selling price, promotional event count and flag, incoming stock volume (receipts_qty), current inventory level (stock), out-of-stock flags, and period-over-period growth rates. Products with fewer than three months of history are excluded, as this is the minimum required for lag and rolling mean features.

Models. (1) Naive seasonal baseline — the minimum performance threshold, predicting each month's sales as the average of all same-calendar-month observations in the training set. (2) OLS linear regression — tests whether a linear combination of features suffices. (3) SARIMAX$(1,0,1)(1,1,0)_{12}$ with price and promotions as exogenous regressors — the classical statistical benchmark. (4) XGBoost (max_depth = 6, n_estimators = 500, learning_rate = 0.05). (5) LightGBM (num_leaves = 31, n_estimators = 500, learning_rate = 0.05). Gradient boosting models use the log-transformation of equation (8) and 5-fold time-series cross-validation for hyperparameter selection.

Evaluation metrics. All models are evaluated using four metrics:

$$\text{MAE} = \frac{1}{n}\sum_{i=1}^{n}|y_i - \hat{y}_i| \quad (9)$$

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_i - \hat{y}_i)^2} \quad (10)$$

$$\text{MAPE} = \frac{100}{n}\sum_{i=1}^{n}\frac{|y_i - \hat{y}_i|}{|y_i|} \quad (11)$$

$$R^2 = 1 - \frac{\sum(y_i - \hat{y}_i)^2}{\sum(y_i - \bar{y})^2} \quad (12)$$

y_i are the true sales values, $\hat{y}_i$ are the model predictions, and $\bar{y}$ is the mean of true values. RMSE and R^2 are the primary metrics because MAPE (equation 11) is unstable when $y_i \approx 0$, which occurs for products with sporadic demand in the test set.

Fig. 1. Research methodology pipeline: from raw data to model evaluation

5. Feature Engineering Framework

A feature engineering framework was constructed producing 32 input features in five groups. The goal is to give the model explicit access to every source of systematic variation identified in Section 3: seasonal structure, trend, price effects, promotional lift, and inventory constraints.

Group 1 — Lag features. Lag features give the model direct access to past sales: lag_k(t) = Y_{t−k}, with k ∈ {1, 2, 3, 6, 12}. The lag-12 feature is the most important temporal feature — it captures same-calendar-month demand from the prior year, directly encoding the annual seasonal cycle identified by the Spearman analysis (equation 5). An additional price_lag_1 feature captures the previous month's selling price.(for each countries there ara

Group 2 — Rolling statistics. Rolling means at 3-, 6-, and 12-month windows provide smooth demand estimates: rolling_mean_W(t) = (1/W) $\Sigma^{W}_{j=1}$ Y_{t−j}. Two dynamic features capture short-term change: sales_diff_1 = Y_t − Y_{t−1} (month-over-month difference) and stock_to_roll3 = stock_t / rolling_mean_3(t) (inventory coverage ratio), which serves as a stockout risk indicator.

Group 3 — Cyclic calendar encoding. Month is encoded as sine and cosine transformations:

$$\text{month\_sin} = \sin\left(\frac{2\pi \cdot \text{month}}{12}\right) \quad (13)$$

$$\text{month\_cos} = \cos\left(\frac{2\pi \cdot \text{month}}{12}\right) \quad (14)$$

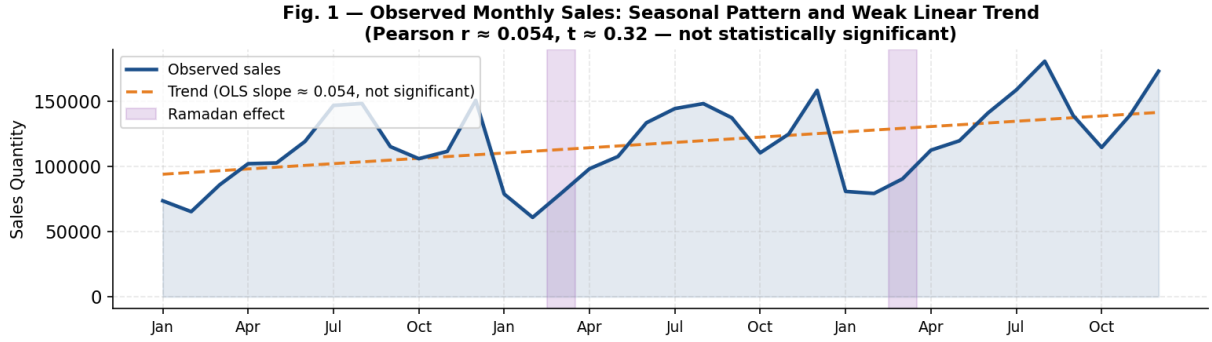
Equations (13)–(14) map the twelve months onto a unit circle so that December and January are adjacent — a property that a plain integer encoding violates. Two locally specific features are added: official public holidays per month, and a binary Ramadan indicator I_Ramadan(t) ∈ {0, 1}. Ramadan produces a sharp demand spike for dates and beverages that is invisible to Gregorian-calendar-only models.

Group 4 — Price and promotional features. Current selling price (rc_price), price-to-median ratio, promotional event count (promo_count), promotional flag, and a price × promo interaction term capturing the combined elasticity effect of simultaneous price reduction and promotion.

Group 5 — Inventory and operational features. Incoming stock volume (receipts_qty), current inventory level (stock), stock adequacy flags, and a product-specific trend index $\hat{\beta}$_trend = $\Sigma(t - \bar{t})(Y_t - \bar{Y}) / \Sigma(t - \bar{t})^2$ computed as the OLS slope over the training period.

6. Results and Discussion

6.1 Preliminary data analysis. Figure 2 presents the observed monthly sales series and the seasonal index derived from the decomposition of equation (1).



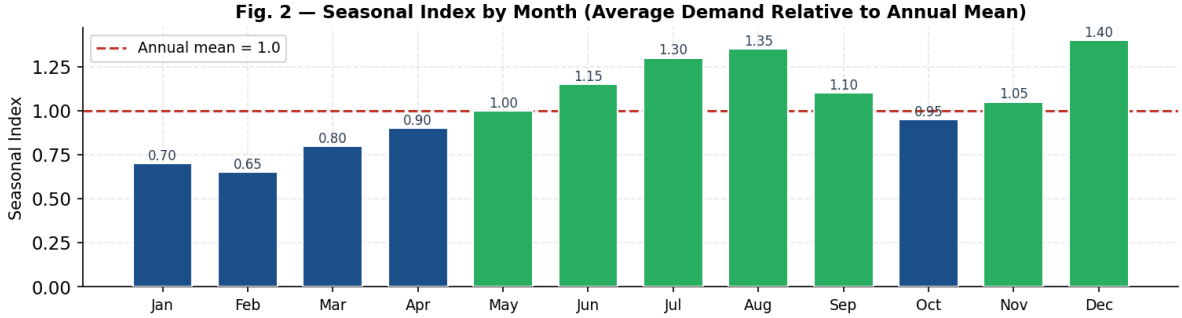


Fig. 2. Monthly sales pattern (top) and seasonal index by calendar month (bottom)

The top panel shows the observed time series with an OLS trend line. The line is nearly flat — consistent with the Pearson finding ($r \approx 0.054$, $t \approx 0.32$, not significant, equation 4). The bottom panel shows the seasonal index: the ratio of average monthly demand to the annual mean. July and August peak at index ≈ 1.30–1.35, while January and February are weakest at ≈ 0.65–0.70. The Ramadan months (highlighted) show a visible spike for date and beverage categories, confirming the value of the Ramadan indicator in Group 3.

Figure 3 confirms the core mathematical finding of Section 3: near-zero Pearson correlations versus strong Spearman correlations across all product categories.

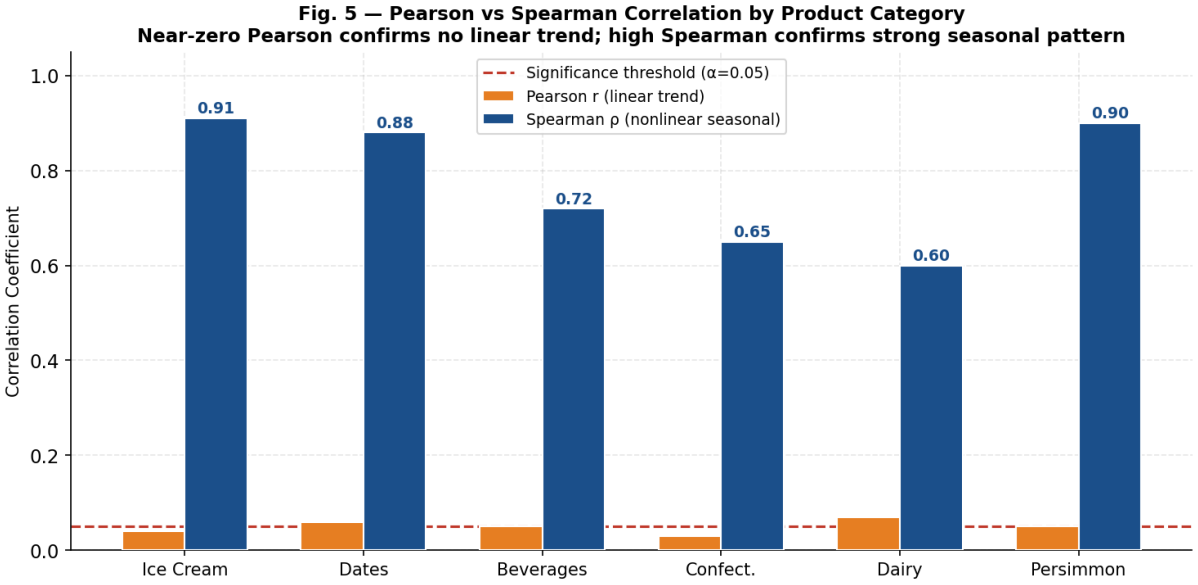


Fig. 3. Pearson r vs Spearman ρ correlation by product category

Orange bars (Pearson r, equation 3) are near zero for all categories, confirming the absence of significant linear trend. Blue bars (Spearman ρ, equation 5) range from 0.60 to 0.91, confirming strong nonlinear seasonal structure. The contrast directly justifies gradient boosting over linear regression or ARIMA. The Spearman correlation is highest for ice cream (0.91) and persimmon (0.90) — products with sharp, concentrated seasonal peaks — and lowest for beverages (0.60), which have a flatter year-round demand profile.

6.2 Model performance comparison. Table 1 presents the complete out-of-sample results on the held-out test set, evaluated on metrics (9)–(12).

Table 1

Complete model performance comparison on the hold-out test set

Model	MAE	RMSE	MAPE (%)	R^2
Naive Baseline	316,563	1,665,342	—	—
Linear Regression	80,255	98,132	40.05	0.567
SARIMAX *	198.2 *	1,620.5 *	—	—
XGBoost	135.94	2,103	25.8	0.72
LightGBM ✓ BEST	**141.03**	**1,996**	**50.4 ****	**0.81**

** SARIMAX MAE and RMSE are on the log-transformed scale and are not directly comparable with other models.*
*** LightGBM MAPE is inflated by zero-sales test observations; R^2 and RMSE (equations 10, 12) are the primary metrics.*

Fig. 3 — Comparative Model Performance on Hold-out Test Set

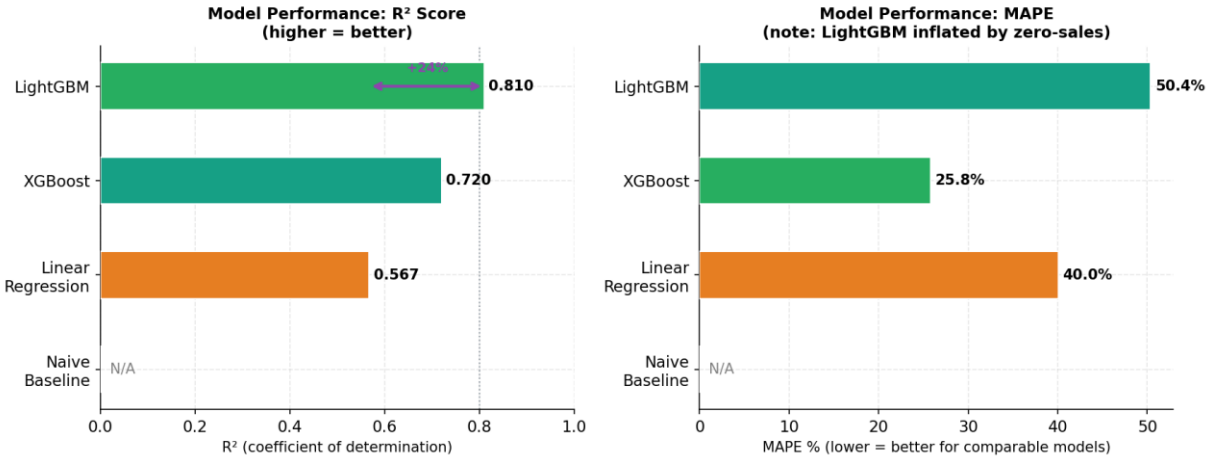


Fig. 4. Comparative model performance: R² (left) and MAPE (right) on hold-out test set

LightGBM achieves $R^2 = 0.81$ and RMSE = 1,996 — the best result on both primary metrics. XGBoost achieves the lowest MAPE (25.8%) and MAE (135.94) but a lower R^2 (0.72). Both gradient boosting models substantially outperform SARIMAX, OLS regression ($R^2 = 0.567$), and the naive baseline.

Linear regression exhibits four specific failure modes. First, it produces negative sales predictions for low-volume products because the OLS objective has no non-negativity constraint. Second, it cannot capture the asymmetric seasonal spikes of products like ice cream and dates, where the summer peak is far steeper than the winter trough. Third, multicollinearity among lag features inflates coefficient variance. Fourth — most importantly — it cannot represent interaction effects: the combined demand lift of a promotion during peak season is larger than the sum of the two individual effects, a pattern that gradient boosting captures through tree-split interactions. These four limitations together account for the full 24-percentage-point gap between $R^2 = 0.567$ and $R^2 = 0.81$.

SARIMAX tracks individual product seasonal patterns through the seasonal AR and MA terms of equation (6), but shows systematic residual bias: overestimating spring recovery by approximately 12% and underestimating autumn decline by approximately 9%. This reflects the limitation of linear time series models when demand is also driven by concurrent business actions — promotions and stock decisions — that the exogenous variable specification of SARIMAX does not fully represent.

6.3 Feature importance analysis. Table 2 and Figure 5 present the top ten predictors by LightGBM gain importance.

Table 2

Top 10 features by LightGBM importance score (gain)

Rank	Feature	What it means
1	receipts_qty	Incoming stock volume — strongest single demand predictor
2	subgroup_encoded	Product category — captures category-specific seasonal shape
3	rc_price	Current selling price — price-elasticity effects
4	price_lag_1	Previous month price — detects price changes and promotions
5	lag_1	Previous month sales — captures short-term momentum
6	promo_count	Number of promotional events — quantifies demand lift
7	stock	Current inventory level — captures stock-constrained demand
8	stock_to_roll3	Stock coverage ratio — stockout risk indicator
9	rolling_mean_12	12-month rolling mean — trend-adjusted demand baseline
10	sales_diff_1	Month-over-month sales change — short-term trajectory

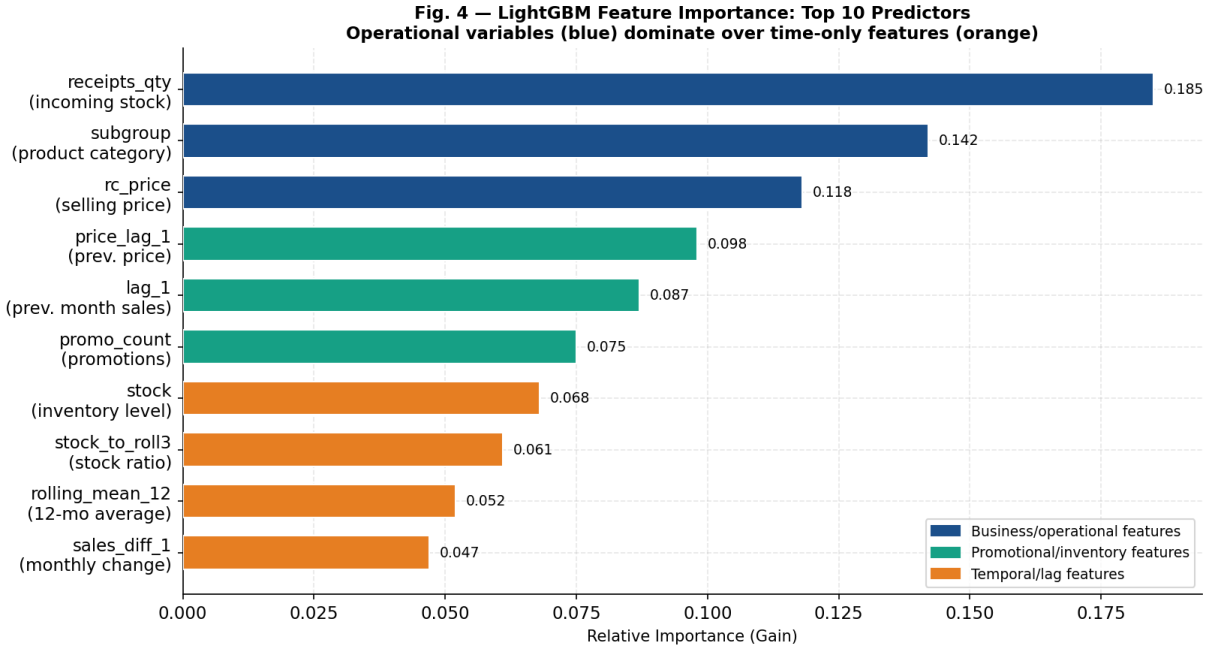


Fig. 5. LightGBM feature importance: top 10 predictors by gain

The most important predictor is receipts_qty (incoming stock volume, importance = 0.185) — more than the next two features combined. Experienced buyers order more when they expect high demand, encoding forward-looking procurement intelligence that no time-series model can capture. This is the single most practically significant finding of the study.

Product sub-category (subgroup_encoded, 0.142) is second, reflecting the dramatically different seasonal profiles across product types: ice cream (Spearman $\rho \approx 0.91$) versus beverages ($\rho \approx 0.60$). Selling price (rc_price, 0.118) and its lag (price_lag_1, 0.098) jointly contribute 0.216 — the largest combined contribution — confirming significant price elasticity. The purely temporal features (lag_1 at rank 5, rolling_mean_12 at rank 9, sales_diff_1 at rank 10) account for only 0.186 combined, less than the single business variable receipts_qty. This confirms the central finding: business-context variables carry substantially more predictive weight than time series structure alone.

7. Conclusions

This study comparatively evaluated five forecasting approaches for monthly retail sales, using real operational data from a Kazakhstani retail business and explicit mathematical characterisation of trend and seasonal components. Four findings stand out.

Finding 1 — No significant linear trend, strong seasonal structure. Pearson $r \approx 0.054$ ($t \approx 0.32 < t\_crit \approx 2.032$, equation 4) rules out linear trend models. Spearman $r_s \approx 0.68–0.90$ (equation 5) confirms strong nonlinear seasonality. These two tests together justify gradient boosting over ARIMA or linear regression.

Finding 2 — Operational variables dominate. Incoming stock volume, product category, and selling price are more predictive than any temporal feature. Demand is shaped equally by business decisions and the calendar — a fact that only becomes visible through feature importance analysis.

Finding 3 — LightGBM is substantially superior. $R^2 = 0.81$ versus $R^2 = 0.567$ for OLS regression — a 24-percentage-point gap that directly quantifies the value of nonlinear interaction modelling. LightGBM outperforms SARIMAX, OLS, XGBoost ($R^2 = 0.72$), and the naive baseline on the primary metrcs.

Finding 4 — The two-phase approach matters. Mathematical correlation analysis before modelling is not merely cosmetic: the Spearman test is the specific reason equations (13)–(14) and the Ramadan indicator were included in the feature set, and those features are among the top predictors. Domain reasoning encoded as features is a necessary complement to algorithmic power.

For businesses in Kazakhstan: record incoming stock quantities, inventory levels, and promotional activity; use LightGBM for products with three or more months of history; encode the Ramadan effect explicitly; retain SARIMAX or exponential smoothing only for data-sparse products. Future work should address probabilistic forecasting via quantile regression for safety stock optimisation, global cross-product models that exploit demand correlations across the portfolio, and systematic comparison with LSTM and Transformer architectures.

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ON NONSMOOTH PROBLEMS OF MATHEMATICAL PROGRAMMING

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О НЕГЛАДКИХ ЗАДАЧАХ МАТЕМАТИЧЕСКОГО ПРОГРАММИРОВАНИЯ

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Abstract

This paper derives necessary first and second-order extremum conditions for nonsmooth extremal problems with constraints in a Fréchet space. It also derives an analog of the Kuhn-Tucker theorem for a mathematical programming problem in a Fréchet space in the case of an operator constraint with equality. It also derives a second-order necessary extremum condition for nonsmooth mathematical programming problems, which is an analog of the second-order Levitin-Milyutin-Osmolovskii theorem.

Аннотация

В работе получены необходимые условия экстремума первого и второго порядка для негладких экстремальных задач при наличии ограничений в пространстве Фреше. В работе получен аналог теоремы Куна-Таккера для задачи математического программирования в пространстве Фреше в случае операторного ограничения с равенством. В работе также получено необходимое условие экстремума второго порядка для негладких задачи математического программирования, являющееся аналогом теоремы Левитина-Милютина-Осмоловского второго порядка.

Keywords: function, subdifferential, space, necessary condition.
Ключевые слова: функция**,** субдифференциал, пространство, необходимое условие.

1.Введение

В задаче минимизации с ограничениями при получении необходимых и достаточных условий экстремума, важную роль играет построение функций точного штрафа. В задаче выпуклого программирования функция точного штрафа построена Куна-Таккером в [1]. В задаче математического программирования функция точного штрафа рассмотрена в книгах [2-6]. Используя теорему Фана в конечномерном пространстве, в [5] было получено необходимое условие оптимальности решения гладких задачи математического программирования. В данной работе доказываем аналог теоремы Фана в пространстве Фреше в случае аффинного операторного ограничения с равенством, и используя его, доказываем аналог теоремы Куна-Таккера для задачи математического программирования в пространстве Фреше в случае аффинного операторного ограничения с равенством. В работе, используя понятию верхней аппроксимации в точке, также получены необходимые условия первого и второго порядка для негладкой задачи математического программирования. Данная работа является обобщением и продолжением работы [7].

Работа состоит из двух пунктов. В п.1 получены необходимые условия экстремума первого порядка для экстремальных задач с ограничением. В п.2 получены необходимые условия экстремума второго порядка для экстремальных задач с ограничением.

1. О небходимых условиях первого порядка

Пусть (X,d) -метрическое пространство, Y -нормированное пространство, G, $C\subset X$, $F:X\to Y$, $f:X\to R$, $\nu>0$, $\delta>0$ и $R_+=[0,+\infty)$. Положим $B(x,\delta)=\{y\in X: d(x,y)\le\delta\}$.

Если отображение F удовлетворяет условию $\|F(y)-F(x)\|\le Kd(x,y)^{\nu}$ при $x,y\in G$, то будем говорить, что F удовлетворяет условию Гельдера порядка ν, $0<\nu\le 1$, на множестве G с постоянной K.

Если функция f удовлетворяет условию $|f(y)-f(x)|\le Kd(x,y)^{\nu}$ при $x,y\in B(\bar{x},\delta)$, то будем говорить, что f удовлетворяет условию Гельдера порядка ν, $0<\nu\le 1$, на множестве $B(\bar{x},\delta)$ с постоянной K.

Положим $d_C(x)=\inf\{d(x,y): y\in C\}$, $S_\lambda(x)=f(x)+\lambda d_C^{\nu}(x)$ (см.[8, с.206]).

Теорема 1. Пусть x_0 является минимумом функции f на множестве C, f удовлетворяет условию Гельдера порядка ν на множестве G с постоянной K и $C\subset G$. Тогда для любого $\lambda\ge K$ функция $S_\lambda(x)=f(x)+\lambda d_C^{\nu}(x)$ достигает минимума на G в точке x_0 и если $\lambda>K$ и C замкнуто, то любая точка минимизирующая $S_\lambda(x)$ на множестве G принадлежит в C.

Доказательство. Предположим противное. Пусть существуют точка $y\in G$ и число $\varepsilon>0$ такие, что $S_\lambda(y)<f(x_0)-\lambda\varepsilon$, где $\lambda\ge K$. Возьмем точку $c\in C$ такую, что $d(y,c)^{\nu}\le d_C^{\nu}(y)+\varepsilon$. Так как f удовлетворяет условию Гельдера порядка ν на G с постоянной K, то

$$f(c)\le f(y)+Kd(c,y)^{\nu}\le f(y)+\lambda d(c,y)^{\nu}\le f(y)+\lambda d_C^{\nu}(y)+\lambda\varepsilon<f(x_0).$$

Это противоречит предположению, что f достигает минимума в точке x_0 на множестве C.

Если $\lambda>K$ и $y\in G$ также минимизирует функции $S_\lambda(x)$ на множестве G, то из первой части теоремы получим $f(y)+\lambda d_C^{\nu}(y)=f(x_0)\le f(y)+\frac{\lambda+K}{2}d_C^{\nu}(y)$. Отсюда получим, что $d_C^{\nu}(y)=0$. Поэтому $d_C(y)=0$. Так как C замкнуто, то $y\in C$. Теорема доказана.

Следствие 1. Пусть x_0 является минимумом функции f на множестве C, f удовлетворяет условию Гельдера порядка ν на множестве $B(x_0,\delta)$ с постоянной K и $C\subset B(x_0,\delta)$. Тогда для любого $\lambda\ge K$ функция $S_\lambda(x)=f(x)+\lambda d_C^{\nu}(x)$ достигает минимума на множестве $B(x_0,\delta)$ в точке x_0 и если $\lambda>K$ и C замкнуто, то любая точка, минимизирующая $S_\lambda(x)$ на множестве $B(x_0,\delta)$, принадлежит C.

Рассмотрим непосредственное обобщение теоремы Фана, которая применяется для получения необходимых условий в задаче математического программирования.

Лемма 1. Пусть Z линейное пространство, $C\subset Z$ выпуклое пространство, $f_i:C\to R$, $i=\overline{1,k}$, выпуклые функции, $f_i:Z\to R$, $i=\overline{k+1,m}$, аффинные функции и система

$$f_i(x)<0,\quad i=\overline{1,k} \tag{1}$$

$$f_i(x)=0,\quad i=\overline{k+1,m} \tag{2}$$

не имеет решения на множестве C, тогда существуют числа $\lambda_1\ge 0,...,\lambda_k\ge 0$, $\lambda_{k+1},\cdots,\lambda_m$ такие, что выполняется неравенство $\sum_{i=1}^{m}\lambda_i f_i(x)\ge 0$ при $x\in C$.

Доказательство. Обозначив $u=(u_1,\dots,u_m)$ рассмотрим множества

$$U_1=\{u\in R^m:\exists x\in C,\ \text{что } f_i(x)\le u_i,\ i=\overline{1,k},\ f_i(x)=u_i,\ i=\overline{k+1,m}\},$$

$$U_2=\{u\in R^m: u_i<0,\ i=\overline{1,k},\ u_i=0,\ i=\overline{k+1,m}\}.$$

Так как системы (1) и (2) не имеет решения на множестве C имеем, что $U_1\cap U_2=\varnothing$. Отсутствие решений систем (1) и (2), означает, что $U_1\cap U_2=\varnothing$. Действительно, если $(\bar{u},\bar{\upsilon})\in U_1\cap U_2$, то существует вектор $\bar{x}\in C$ такой, что $f_i(\bar{x})\le\bar{u}_i$, $i=1,\dots,k$, $f_i(\bar{x})=\bar{u}_i$, $i=k+1,\dots,m$, $\bar{u}_i<0$, $i=1,\dots,k$, $\bar{u}_i=0$, $i=k+1,\dots,m$. Отсюда следует, что $f_i(\bar{x})<0$, $i=1,\dots,k$, $f_i(\bar{x})=0$, $i=k+1,\dots,m$ и $\bar{x}\in C$. Получаем противоречие. Легко проверяется, что множества U_1 и U_2 выпуклые. Тогда из теоремы отделимости следует, что существует вектор $y\in R^m$, $y\ne 0$ такой, что $\langle y,u\rangle\ge\langle y,\upsilon\rangle$ при $u\in U_1$ и $\upsilon\in U_2$, т.е. выполняется неравенство

$$\sum_{i=1}^{m}y_iu_i\ge\sum_{i=1}^{k}y_i\upsilon_i \tag{3}$$

при $u \in U_1$ и $\upsilon_1 \le 0, \cdots \upsilon_k \le 0$. Если $\upsilon_1 \to -\infty, \cdots \upsilon_k \to -\infty$, то отсюда следует, что $y_1 \ge 0, \cdots y_k \ge 0$. Для любого $x \in C$ рассмотрим вектор $u \in R^m$ с координатами $u_i = f_i(x),\ i = \overline{1,k}$, $u_i = f_i(x), \quad i = \overline{k+1,m}$. Ясно, что $u \in U_1$. Положив $\upsilon_1 = 0, \cdots \upsilon_k = 0$ в (3) и $f_i(x) = u_i,\ i = \overline{1,m}$ при $x \in C$ получим, что $\sum\limits_{i=1}^{m} y_i f_i(x) \ge 0$ при $x \in C$. Лемма доказана.

Пусть Z линейное пространство, $C \subset Z$ выпуклое множество, $f_i : C \to R,\ i = 0, \overline{1,k}$, линейные функции, $f_i : Z \to R, \quad i = \overline{k+1,m}$, аффинные функции.

Рассмотрим задачу

$$f_0(x) \to \min \tag{4}$$

$$f_i(x) \le 0, \quad i = \overline{1,k} \tag{5}$$

$$f_i(x) = 0, \quad i = \overline{k+1,m},\ x \in C \tag{6}$$

Теорема 2. Если Z линейное пространство, $C \subset Z$ выпуклое множество, $f_i : C \to R, \quad i = \overline{1,k}$, выпуклые функции, $f_i : Z \to R, \quad i = \overline{k+1,m}$, аффинные функции и x_0 -точка минимума в задаче (4)-(6), то существуют числа $\lambda_0, \lambda_1 \ge 0, ..., \lambda_k \ge 0, \lambda_{k+1}, \cdots, \lambda_m$ не равные нулю одновременно такие, что выполняется неравенство $\lambda_0(f_0(x) - f_0(x_0)) + \sum\limits_{i=1}^{m} \lambda_i f_i(x) \ge 0$ при $x \in C$.

Доказательство. Ясно, что система $f_0(x) - f_0(x_0) < 0,\ f_i(x) < 0,\ i = \overline{1,k},\ f_i(x) = 0,\ i = \overline{k+1,m}$ не имеет решения на множестве C. Тогда по лемме 1 существуют числа $\lambda_0 \ge 0, \lambda_1 \ge 0, ..., \lambda_k \ge 0, \lambda_{k+1}, \cdots, \lambda_m$ не равные нулю одновременно такие, что выполняется неравенство $\lambda_0(f_0(x) - f_0(x_0)) + \sum\limits_{i=1}^{m} \lambda_i f_i(x) \ge 0$ при $x \in C$. Лемма доказана.

Рассмотрим бесконечную версию теоремы Фана, которая применяется для получения необходимых условий в задаче математического программирования.

Лемма 2. Пусть X и Y - пространства Фреше, $C \subset X$ - выпуклое множество и $\operatorname{int} C \ne \varnothing$, $f_i : C \to R$, $i = 1, \ldots, k,$ - выпуклые непрерывные функции, $A : X \to Y$ -непрерывный аффинный оператор, т. е. $Ax = \Lambda x + \bar{y}$, где $\Lambda : X \to Y$ -непрерывный линейный оператор, $\bar{y} \in Y$, $\operatorname{Im} \Lambda = Y$ и система

$$f_i(x) < 0, \quad i = 1, \ldots, k,\ Ax = 0 \tag{7}$$

не имеет решения в множестве C. Тогда существуют одновременно ненулевые числа $\lambda_1 \ge 0, ..., \lambda_k \ge 0$ и $y^* \in Y^*$ такие, что

$$\sum_{i=1}^{k} \lambda_i f_i(x) + \langle y^*, Ax \rangle \ge 0 \tag{8}$$

при $x \in C$.

Доказательство. Обозначим $u = (u_1, \ldots, u_k)$. Рассмотрим множества

$$U_1 = \{(u, \upsilon) \in R^k \times Y :\ f_i(x) \le u_i,\ i = 1, \ldots, k,\ A(x) = \upsilon \text{ при некоторых } x \in C\},$$

$$U_2 = \{(u, \upsilon) \in R^k \times Y : u_i < 0,\ i = 1, \ldots, k,\ \upsilon = 0\}.$$

Отсутствие решений системы (7) означает, что $U_1 \cap U_2 = \varnothing$. Действительно, если $(\bar{u}, \bar{\upsilon}) \in U_1 \cap U_2$, то существует вектор $\bar{x} \in C$ такой, что $f_i(\bar{x}) \le \bar{u}_i,\ i = 1, \ldots, k,\ A(\bar{x}) = \bar{\upsilon},\ \bar{u}_i < 0,\ i = 1, \ldots, k,\ \bar{\upsilon} = 0$. Отсюда следует, что $f_i(\bar{x}) < 0,\ i = 1, \ldots k,\ A(\bar{x}) = 0$ и $\bar{x} \in C$. Получаем противоречие. Поэтому $U_1 \cap U_2 = \varnothing$. Непосредственно проверяется, что U_1 и U_2 являются выпуклыми множествами. Покажем, что $\operatorname{int} U_1 \ne \varnothing$. Метрика в X обозначается d_1. Пусть $\bar{x} \in \operatorname{int} C$. Так как $\operatorname{Im} \Lambda = Y$, тогда по теореме об открытом отображении 2.2.1 [9, с.68] Λ является открытым отображением. Если $\bar{x} \in \operatorname{int} C$, то существует $\delta_1 > 0$ такое, что $U(\bar{x}, \delta_1) = \{x \in X : d_1(x, \bar{x}) < \delta\} \subset \operatorname{int} C$. Тогда $A(U(\bar{x}, \delta_1)) = \Lambda(U(\bar{x}, \delta_1)) + \bar{y}$ открытое множество и $A(U(\bar{x}, \delta_1)) \subset A(C)$. По условию $f_i(x),\ i = 1, \ldots, k$, непрерывные функции в точке $\bar{x}$. Пусть $\varepsilon > 0$. Тогда существует число $\delta_2 > 0$ такое, что $|f_i(x) - f_i(\bar{x})| \le \varepsilon$ при $d_1(x, \bar{x}) = d_1(x - \bar{x}, 0) < \delta_2$ и $i = 1, \ldots, k$. Отсюда следует, что $f_i(x) \le f_i(\bar{x}) + \varepsilon$ для $d_1(x, \bar{x}) \le \delta_2$. Положив $f = (f_1, \ldots, f_k),\ \delta = \min\{\delta_1, \delta_2\}$, получим, что $\{u \in R^k : f(\bar{x}) + (\varepsilon, \ldots, \varepsilon) \le u\} \times A(U(\bar{x}, \delta)) \subset U_1$, т.е. $\operatorname{int} U_1 \ne \varnothing$. По теореме об отделимости (см. теорему

3.2.5[10, с.160]) существует вектор $(\lambda_1,...,\lambda_k,y^*)\in R^k\times Y^*$, отличный от нуля, такой что $\langle\lambda,u\rangle+\langle y^*,\upsilon\rangle\ge\langle\lambda,\tilde{u}\rangle+\langle y^*,\tilde{\upsilon}\rangle$ при $(u,\upsilon)\in U_1$ и $(\tilde{u},\tilde{\upsilon})\in U_2$.

Из этого следует, что

$$\sum_{i=1}^{k}\lambda_i u_i+\langle y^*,\upsilon\rangle\ge\sum_{i=1}^{k}\lambda_i\tilde{u}_i \tag{9}$$

при $(u,\upsilon)\in U_1$, $\tilde{u}_1\le 0,\dots,\tilde{u}_k\le 0$. Тогда при $\tilde{u}_1\to-\infty,\cdots\tilde{u}_k\to-\infty$ получим, что $\lambda_1\ge 0,\cdots,\lambda_k\ge 0$. Для любого $x\in C$ рассмотрим вектор (u,υ), где $u_i=f_i(x)$, $i=1,\dots,k$, $\upsilon=A(x)$. Очевидно, что $(u,\upsilon)\in U_1$. Подставляя этот вектор в (9) и полагая $\tilde{u}_1=0,\dots,\tilde{u}_k=0$, приходим к (8). Лемма доказана.

Отметим, что в лемме 2 условие, $f_i:C\to R$, $i=1,\dots,k$, «выпуклые непрерывные функции» можно заменить условием, $f_i:C\to R$, $i=1,\dots,k$, «выпуклые полунепрерывные снизу функции». В лемме 2 условие $f_i:C\to R$, $i=1,\dots,k$, «выпуклые непрерывные функции» можно заменить условием «выпуклые функции $f_i:C\to R$, $i=1,\dots,k$, непрерывны в точке $\bar{x}\in\operatorname{int}C$».

Лемма 3. Если X и Y пространства Фреше, $C\subset X$ выпуклое множество и $\operatorname{int}C\ne\varnothing$, $\varphi_i:C\to R$, $i=0,1,\dots,m$, выпуклые непрерывные функции, $\Lambda:X\to Y$ линейный непрерывный оператор, $Ax=\Lambda x+\bar{y}$, $\bar{y}\in Y$, $\operatorname{Im}\Lambda=Y$ и система

$$\varphi_0(x)<0,\ \varphi_1(x)<0,\ \dots,\ \varphi_m(x)<0,\ Ax=0,$$

не имеет решения на множестве C, а система $\varphi_1(x)<0$, $\dots$, $\varphi_m(x)<0$, $Ax=0$ имеет решения на множестве C и существует точка $\bar{x}\in\operatorname{int}C$ такая, что $A\bar{x}=0$, то существуют $\alpha_1\ge 0,\dots,\alpha_m\ge 0$ и $y^*\in Y^*$ такие, что $\varphi_0(x)+\sum_{i=1}^{m}\alpha_i\varphi_i(x)+\langle y^*,Ax\rangle\ge 0$ при $x\in C$.

Доказательство. По лемме 2 существуют одновременно не равные нулю $\alpha_0\ge 0$, $\alpha_1\ge 0,\dots,\alpha_m\ge 0$ и $y^*\in Y^*$ такие, что $\sum_{i=0}^{m}\alpha_i\varphi_i(x)+\langle y^*,Ax\rangle\ge 0$ при $x\in C$. Пусть $\alpha_0=0$ и среди чисел $\alpha_1\ge 0,...,\alpha_m\ge 0$ есть положительные и пусть точка $\tilde{x}\in C$ такая, что $\varphi_i(\tilde{x})<0$, $i=1,\dots,m$, $A\tilde{x}=0$. Тогда имеем, что $\sum_{i=1}^{m}\alpha_i\varphi_i(\tilde{x})+\langle y^*,A\tilde{x}\rangle<0$. Так как $\sum_{i=0}^{m}\alpha_i\varphi_i(x)+\langle y^*,Ax\rangle\ge 0$ при $x\in C$, то получим противоречие. Если $\alpha_1=0,...,\alpha_m=0$, то имеем, что $\langle y^*,Ax\rangle\ge 0$ при $x\in C$. Так как по условию $\operatorname{Im}\Lambda=Y$, то получим, что $\operatorname{Im}A=Y$. Тогда из неравенства $\langle y^*,Ax\rangle\ge 0$ при $x\in C$ следует, что $\langle y^*,\Lambda x-\Lambda\bar{x}\rangle\ge 0$ при $x\in C$. Поэтому $\langle\Lambda^*y^*,z\rangle\ge 0$ при $z\in C-\bar{x}$. Так как $0\in\operatorname{int}(C-\bar{x})$ то имеем, что $\Lambda^*y^*=0$. По условию $\operatorname{Im}\Lambda=Y$, поэтому получим, что $\ker\Lambda^*=(\operatorname{Im}\Lambda)^{\perp}=\{0\}$. Отсюда следует, что $y^*=0$. Поэтому получим, что $\alpha_0=0$, $\alpha_1=0,...,\alpha_m=0$, $y^*=0$. Получим противоречие. Тогда получим, что $\alpha_0>0$. Поэтому $\varphi_0(x)+\sum_{i=1}^{m}\frac{\alpha_i}{\alpha_0}\varphi_i(x)+\langle\frac{1}{\alpha_0}y^*,Ax\rangle\ge 0$ при $x\in C$. Обозначив $\bar{y}^*=\frac{1}{\alpha_0}y^*$ и $\bar{\alpha}_i=\frac{\alpha_i}{\alpha_0}$ имеем, что $\varphi_0(x)+\sum_{i=1}^{m}\bar{\alpha}_i\varphi_i(x)+\langle\bar{y}^*,Ax\rangle\ge 0$ при $x\in C$. Лемма доказана.

Пусть X и Y - банаховы пространства, $f_i:X\to R$, $i\in I=\{0,1,\dots,m\}$, $J=\{1,\dots,m\}$, $F:X\to Y$, $C\subset X$.

Рассмотрим задачу

$$f_0(z)\to\min,\quad z\in\{x\in X:f_i(x)\le 0,\ i=1,\dots,m,\ F(x)=0,\ x\in C\}. \tag{10}$$

Пусть $I_C(x_0)$ ($T_C(x_0)$) множество всех гиперкасательных (касательных) к множеству C в точке $x_0\in C$ и $N_C(x_0)=T_C^-(x_0)$ (см.[2, с.59, с.54]).

Отметим, что (см.[2, с.56])

$T_C(x_0)=\{\upsilon\in X:\forall h_n>0,\ h_n\to 0,\forall x_n\to x_0,\exists u_n\to\upsilon,x_n+h_nu_n\in C\text{ при }n\in N\}$,

$I_C(x_0)=\{\upsilon\in X:\exists\varepsilon>0\ \text{that}\ y+t\omega\in C\ \text{at}\ y\in(x+\varepsilon B)\cap C,\ \omega\in\upsilon+\varepsilon B,\ t\in(0,\varepsilon)\}$.

Если существуют функции $\varphi:X\to R$ и $o:R_+\to R_+$, где $\lim_{t\downarrow 0}\frac{o(t)}{t}=0$ такие, что

$$f(\bar{x}+x)-f(\bar{x})-\varphi(x)\le o(\|x\|^{\beta})$$

при $x \in X$, $\|x\| \le \delta$, то функцию φ назовем $\varphi - (o(\beta), \delta)$ верхней аппроксимацией функции $f : X \to R$ в точке $\overline{x}$.

Следующая теорема взята из препринта [11] (см. теорему 4).

Теорема 3. Если X и Y банаховы пространства, x_0 -точка локального минимума в задаче (10), функции f_i имеют $\varphi_i - (o_i(1), \delta)$ верхнюю аппроксимацию в точке x_0 при $i \in I$, $\varphi_i : X \to R$ сублинейные непрерывные функции при $i \in I$, $f_j(x_0) = 0$ при $j \in J$, оператор $F : X \to Y$ строго дифференцируем в точке x_0, $F'(x_0)X = Y$, $C \subset X$, $I_C(x_0) \ne \varnothing$, то существуют одновременно не равные нулю $\alpha_0 \ge 0$, $\alpha_1 \ge 0, \ldots, \alpha_m \ge 0$ и $y^* \in Y^*$ такие, что $\sum_{i=0}^{m} \alpha_i \varphi_i(x) + \langle y^*, F'(x_0)x \rangle \ge 0$ при $x \in T_C(x_0)$.

Доказательство. Обозначим $\Lambda = F'(x_0)$. Покажем, что система

$$\varphi_0(x) < 0,\ \varphi_1(x) < 0,\ \ldots,\ \varphi_m(x) < 0,\ \Lambda x = 0$$

не имеет решения на $I_C(x_0)$. Предположим противное. Пусть существует $\overline{x} \in I_C(x_0)$ такая, что $\varphi_i(\overline{x}) < 0$ при $i \in I$ и $\Lambda\overline{x} = 0$. Так как $\Lambda\overline{x} = F'(x_0)\overline{x} = 0$ и $F'(x_0)X = Y$, то по теореме Люстерника[12, с.41] существуют $\varepsilon > 0$ и отображение $r : [0, \varepsilon] \to X$ такие, что $\frac{r(t)}{t} \to 0$ при $t \downarrow 0$ и $F(x_0 + t\overline{x} + r(t)) = 0$ при $t \in [0, \varepsilon]$. По условию функции f_i имеют $\varphi_i - (o_i(1), \delta)$ верхнюю аппроксимацию в точке x_0, где $i \in I$. Тогда имеем $f_i(x_0 + t\overline{x} + r(t)) - f_i(x_0) - \varphi_i(t\overline{x} + r(t)) \le o_i(\|t\overline{x} + r(t)\|)$

при $t \in [0, \varepsilon]$, $\|t\overline{x} + r(t)\| \le \delta$, $i \in I$. Так как φ_i непрерывная функция, то существует $0 < \delta_0 \le \frac{1}{2}\delta$ такое, что $\left|\varphi_i(\overline{x} + \frac{r(t)}{t}) - \varphi_i(\overline{x})\right| \le \frac{1}{2}\left|\varphi_i(\overline{x})\right|$ при $\left\|\frac{r(t)}{t}\right\| \le \delta_0$ и $i \in I$. Тогда получим, что $\varphi_i(\overline{x} + \frac{r(t)}{t}) \le \frac{1}{2}\varphi_i(\overline{x})$ при $\left\|\frac{r(t)}{t}\right\| \le \delta_0$ и $i \in I$. Так как $\frac{r(t)}{t} \to 0$ при $t \downarrow 0$, то существует λ, где $0 < \lambda < 1$, такое, что $\left\|\frac{r(t)}{t}\right\| \le \delta_0$ при $t \in (0, \lambda]$. Тогда $\|t\overline{x} + r(t)\| \le \delta$ при $t \in [0, \lambda_1]$, где

$\lambda_1 = \min\{\lambda, \frac{1}{2\|\overline{x}\|}\delta, \varepsilon\}$. Поэтому имеем, что

$$f_i(x_0 + t\overline{x} + r(t)) - f_i(x_0) \le 0{,}5\ t\varphi_i(\overline{x}) + o\left(t\left\|\overline{x} + \tfrac{1}{t}r(t)\right\|\right) \le 0{,}5\ t\varphi_i(\overline{x}) + o_i\left(t\left\|\overline{x} + \tfrac{1}{t}r(t)\right\|\right)\frac{t(\|\overline{x}\| + \delta_0)}{t\left\|\overline{x} + \frac{1}{t}r(t)\right\|}$$

при $t \in [0, \lambda_1]$ и $i \in I$. Следовательно, существует число $\lambda_2 > 0$ такое, что

$$f_0(x_0 + t\overline{x} + r(t)) - f_0(x_0) < 0,\ f_j(x_0 + t\overline{x} + r(t)) < 0,\ j \in J,\ F(x_0 + t\overline{x} + r(t)) = 0$$

при $t \in (0, \lambda_2]$. Если $\overline{x} \in I_C(x_0)$, то по определению $I_C(x_0)$ существует $\alpha_0 > 0$ такое, что $x_0 + t\overline{x} + r(t) \in C$ при $t \in [0, \alpha_0]$.

Так как x_0 - точка локального минимума в задаче (10), то получим противоречие.

Поэтому система $\varphi_0(x) < 0$, $\varphi_1(x) < 0$, $\ldots$, $\varphi_m(x) < 0$, $\Lambda x = 0$ не имеет решения на $I_C(x_0)$. По лемме 2 существуют одновременно не равные нулю $\alpha_0 \ge 0, \alpha_1 \ge 0, \ldots, \alpha_m \ge 0$ и $y^* \in Y^*$ такие, что $\sum_{i=0}^{m} \alpha_i \varphi_i(x) + \langle y^*, F'(x_0)x \rangle \ge 0$ при $x \in I_C(x_0)$. Так как $\varphi_i : X \to R$ непрерывные функции при $i \in I$ и $\Lambda = F'(x_0)$ линейный непрерывный оператор, то по теореме 2.4.8[2, с.59] имеем, что

$\sum_{i=0}^{m} \alpha_i \varphi_i(x) + \langle y^*, F'(x_0)x \rangle \ge 0$ при $x \in \mathrm{cl} I_C(x_0) = T_C(x_0)$. Теорема доказана.

Из доказательства теоремы 3 следует, что $\max_{0 \le i \le m} \varphi_i(x) \ge 0$ при $x \in T_C(x_0) \bigcap \mathrm{Ker}\,\Lambda$.

Если существует функция $o : R_+ \to R_+$, где $\lim_{t \downarrow 0} \frac{o(t)}{t} = 0$ такая, что $f(\overline{x} + y) - f(\overline{x}) - \varphi(y) \le o(\|y\|)$ при $y \in \delta B$ и существуют $\sigma(X^*, X)$ компактные множества $\underline{\partial} f(\overline{x})$ и $\overline{\partial} f(\overline{x})$ такие, что $\varphi(x) = \max_{x^* \in \underline{\partial} f(\overline{x})} \langle x^*, x \rangle + \max_{y^* \in \overline{\partial} f(\overline{x})} \langle y^*, x \rangle$, то функция $\varphi : X \to R$ называется $\varphi - (o(1), \delta)$ верхней квазиаппроксимацией функцией $f : X \to R$ в точке $\overline{x}$.

Следствие 2. Если X и Y банаховы пространства, x_0-точка локального минимума в задаче (10), функции f_i имеют $\varphi_i-(o_i(1),\delta)$ верхнюю квазиаппроксимацию в точке x_0, где $i\in I$ и $\varphi_i(y)=\max\limits_{x^*\in\underline{\partial} f_i(\bar{x})}\langle x^*,y\rangle+\min\limits_{y^*\in\overline{\partial} f_i(\bar{x})}\langle y^*,y\rangle$, (т.е. $\varphi_i(y)=p_i(y)+q_i(y)$, $p_i(x)$ и $-q_i(x)$ непрерывные сублинейные функции), $f_j(x_0)=0$ при $j\in J$, оператор $F:X\to Y$ строго дифференцируем в точке x_0, $F'(x_0)X=Y$, $C\subset X$, $I_C(x_0)\neq\varnothing$, то для каждого $y_i^*\in\overline{\partial} f_i(\bar{x})$, $i\in I=\{0,1,\dots,m\}$ существуют одновременно не равные нулю $\alpha_0\geq 0,\ \alpha_1\geq 0,\dots,\alpha_m\geq 0$ и $y^*\in Y^*$ такие, что $\sum\limits_{i=0}^{m}\alpha_i\max\limits_{x^*\in\underline{\partial} f_i(\bar{x})}\langle x^*+y_i^*,x\rangle+\langle y^*,F'(x_0)x\rangle\geq 0$ при $x\in T_C(x_0)$.

Доказательство. Так как функция f_i имеет $\varphi_i-(o_i(1),\delta)$ верхнее квазиаппроксимацие в точке x_0 при $i\in I=\{0,1,\dots,m\}$ и $\varphi_i(y)=\max\limits_{x^*\in\underline{\partial} f_i(\bar{x})}\langle x^*,y\rangle+\min\limits_{y^*\in\overline{\partial} f_i(\bar{x})}\langle y^*,y\rangle$ при $i\in I$, то для каждого $y_i^*\in\overline{\partial} f_i(\bar{x})$, $i\in I=\{0,1,\dots,m\}$, функции f_i имеют $\max\limits_{x^*\in\underline{\partial} f_i(\bar{x})}\langle x^*,y\rangle+\langle y_i^*,y\rangle-(o_i(1),\delta)$ верхнюю аппроксимацию в точке x_0, где $i\in I$, $\max\limits_{x^*\in\underline{\partial} f_i(\bar{x})}\langle x^*,y\rangle+\langle y_i^*,y\rangle$ сублинейные непрерывные функции при $i\in I$. Поэтому справедливость следствия 2 следует из теоремы 3.

Положим $M=\{x\in X:F(x)=0\}$ и $K_M^+(x_0)=\{x\in X:\exists\varepsilon>0,\ \exists r:[0,\varepsilon]\to X$, где $\frac{r(t)}{t}\to 0$ при $t\downarrow 0$, такое, что $F(x_0+tx+r(t))=0$ при $t\in[0,\varepsilon]\}$. Пусть $T_0\subset K_M^+(x_0)$.

Следующая теорема доказывается анологично теореме 3.

Теорема 4. Если X и Y банаховы пространства, x_0-точка локального минимума в задаче (10), функции f_i имеют $\varphi_i-(o_i(1),\delta)$ верхнюю аппроксимацию в точке x_0, где $i\in I$, $\varphi_i:X\to R$ сублинейные непрерывные функции при $i\in I$, $f_j(x_0)=0$ при $j=1,\dots,m$, $T_0\subset K_M^+(x_0)$ выпуклый конус (или $I_C(x_0)\bigcap T_0$ выпуклый конус), $C\subset X$, $I_C(x_0)\bigcap T_0\neq\varnothing$, то существуют одновременно не равные нулю числа $\alpha_0\geq 0,\ \alpha_1\geq 0,\dots,\alpha_m\geq 0$ такие, что $\sum\limits_{i=0}^{m}\alpha_i\varphi_i(x)\geq 0$ при $x\in cl(I_c(x_0)\cap T_0)$.

Пусть отображение $F:U\to Y$ дважды дифференцируемо по Фреше в точке x_0 и подпространство $Z=\operatorname{Im}F'(x_0)=F'(x_0)X$ замкнуто. Положим $V=\operatorname{Im}F'(x_0)\times(Y/\operatorname{Im}F'(x_0))$. Пусть $\pi:Y\to(Y/\operatorname{Im}F'(x_0))$ фактор отображение. Для каждого $h\in X$ рассмотрим отображение $G(x_0,h):X\to V$, определенное по формуле $G(x_0,h)x=(F'(x_0)x,\pi F''(x_0)(h,x))$. Если $\operatorname{Im}G(x_0,h)=V$, то отображение F называется регулярным в точке x_0 на елементе $h\in X$ [13].

Пусть $\widetilde{T}_2\subset\{h\in X:F''(x_0)(h,h)\in\operatorname{Im}F'(x_0),\operatorname{Im}G(x_0,h)=V\}\bigcup\{0\}$ "максимальный выпуклый конус». Через $\overline{\operatorname{Lin}}\,\widetilde{T}_2$ обозначим замыкание множества $\operatorname{Lin}\widetilde{T}_2$. Обозначим $\operatorname{ri}\widetilde{T}_2$ относительное внутренние точки множество $\widetilde{T}_2$ в $\overline{\operatorname{Lin}}\,\widetilde{T}_2$. Положим $\overline{T}_2=\operatorname{cl}\widetilde{T}_2$, $T=T_C(x_0)\bigcap\overline{T}_2$.

Теорема 5. Если X и Y банаховы пространства, x_0-точка локального минимума в задаче (10), функции f_i имеют $\varphi_i-(o_i(1),\delta)$ верхнюю аппроксимацию в точке x_0, где $i\in I$, $\varphi_i:X\to R$ сублинейные непрерывные функции при $i\in I$, $f_j(x_0)=0$ при $j\in J$, отображение $F:X\to Y$ дважды дифференцируемо по Фреше в точке x_0, $Z=\operatorname{Im}F'(x_0)$ замкнуто, $\widetilde{T}_2$ выпуклый конус, $C\subset X$, $I_C(x_0)\bigcap\operatorname{ri}\widetilde{T}_2\neq\varnothing$ и $\Lambda(\overline{\operatorname{Lin}}\,\widetilde{T}_2)$ замкнуто, то существуют одновременно не равные нулю числа $\alpha_0\geq 0,\ \alpha_1\geq 0,\dots,\alpha_m\geq 0$ и $z^*\in Z^*$ такие, что $\sum\limits_{i=0}^{m}\alpha_i\varphi_i(x)+\langle z^*,F'(x_0)x\rangle\geq 0$ при $x\in T$, где $T=T_C(x_0)\bigcap\overline{T}_2$.

Доказательство. Обозначим $\Lambda=F'(x_0)$. Покажем, что система

$$\varphi_0(x)<0,\ \varphi_1(x)<0,\ \dots,\ \varphi_m(x)<0,\ \Lambda x=0$$

не имеет решение на $I_C(x_0)\bigcap\widetilde{T}_2$. Предположим противное. Пусть существует $\bar{x}\in I_C(x_0)\bigcap\widetilde{T}_2$ такая, что $\varphi_i(\bar{x})<0$ при $i\in I$ и $\Lambda\bar{x}=0$. Так как $\Lambda\bar{x}=0$ и $\bar{x}\in\widetilde{T}_2$, то по теореме о поправке[13,с.32] существует

$\varepsilon > 0$ и отображение $r:[0,\varepsilon] \to X$ такие, что $\frac{r(t)}{t} \to 0$ при $t \downarrow 0$ и $F(x_0 + t\bar{x} + r(t)) = 0$ при $t \in [0,\varepsilon]$. По условию функции f_i имеют $\varphi_i - (o_i(1),\delta)$ верхнюю аппроксимацию в точке x_0, где $i \in I$. Тогда $f_i(x_0 + t\bar{x} + r(t)) - f_i(x_0) - \varphi_i(t\bar{x} + r(t)) \le o_i(\|t\bar{x} + r(t)\|)$ при $t \in [0,\varepsilon]$, $\|t\bar{x} + r(t)\| \le \delta$, $i \in I$.

Так как φ_i непрерывная функция, то существует $0 < \delta_0 \le \frac{1}{2}\delta$ такое, что

$\left|\varphi_i(\bar{x} + \frac{r(t)}{t}) - \varphi_i(\bar{x})\right| \le \frac{1}{2}\left|\varphi_i(\bar{x})\right|$ при $\left\|\frac{r(t)}{t}\right\| \le \delta_0$ и $i \in I$. Тогда получим, что $\varphi_i(\bar{x} + \frac{r(t)}{t}) \le \frac{1}{2}\varphi_i(\bar{x})$ при $\left\|\frac{r(t)}{t}\right\| \le \delta_0$ и $i \in I$. Так как $\frac{r(t)}{t} \to 0$ при $t \downarrow 0$, то существует λ, где $0 < \lambda < 1$, такое, что $\left\|\frac{r(t)}{t}\right\| \le \delta_0$ при $t \in (0,\lambda]$. Тогда $\|t\bar{x} + r(t)\| \le \delta$ при $t \in [0,\lambda_1]$, где $\lambda_1 = \min\{\lambda, \frac{1}{2\|\bar{x}\|}\delta, \varepsilon\}$. Поэтому имеем, что

$$f_i(x_0 + t\bar{x} + r(t)) - f_i(x_0) \le 0{,}5\ t\varphi_i(\bar{x}) + o(t\|\bar{x} + \tfrac{1}{t}r(t)\|) \le 0{,}5\ t\varphi_i(\bar{x}) + o_i(t\|\bar{x} + \tfrac{1}{t}r(t)\|)\frac{t(\|\bar{x}\| + \delta_0)}{t\|\bar{x} + \frac{1}{t}r(t)\|}$$

при $t \in [0,\lambda_1]$ и $i \in I$. Следовательно, существует число $\lambda_2 > 0$ такое, что

$$f_0(x_0 + t\bar{x} + r(t)) - f_0(x_0) < 0,\ f_j(x_0 + t\bar{x} + r(t)) < 0 \text{ при } j \in J,\ F(x_0 + t\bar{x} + r(t)) = 0$$

при $t \in (0,\lambda_2]$. Если $\bar{x} \in I_C(x_0)$, то по определению $I_C(x_0)$ существует $\alpha_0 > 0$ такое, что $x_0 + t\bar{x} + r(t) \in C$ при $t \in [0,\alpha_0]$.

Так как x_0 - точка локального минимума в задаче (10), то получим противоречие. Поэтому система $\varphi_0(x) < 0$, $\varphi_1(x) < 0$, …, $\varphi_m(x) < 0$, $\Lambda x = 0$ не имеет решение на $I_C(x_0) \cap \widetilde{T}_2$. Если заменив пространство X через $\overline{\mathrm{Lin}}\,\widetilde{T}_2$ и Y через $\Lambda(\overline{\mathrm{Lin}}\,\widetilde{T}_2)$, то по лемме 2 существуют одновременно не равные нулю $\alpha_0 \ge 0, \alpha_1 \ge 0, \ldots, \alpha_m \ge 0$ и $\Lambda(\overline{\mathrm{Lin}}\,\widetilde{T}_2)^*$ такие, что $\sum_{i=0}^{m}\alpha_i\varphi_i(x) + \langle z^*, F'(x_0)x\rangle \ge 0$ при $x \in I_C(x_0) \cap \widetilde{T}_2$. По теореме Хана-Банаха $Y^*\big|_{\overline{\mathrm{Lin}}\,\widetilde{T}_2} = Z^*\big|_{\overline{\mathrm{Lin}}\,\widetilde{T}_2} = \Lambda(\overline{\mathrm{Lin}}\,\widetilde{T}_2)^*$ (см.[10, с.208]). Так как $\varphi_i : X \to R$ непрерывные функции при $i \in I$ и $\Lambda = F'(x_0)$ линейный непрерывный оператор, то имеем, что $\sum_{i=0}^{m}\alpha_i\varphi_i(x) + \langle z^*, F'(x_0)x\rangle \ge 0$ при $x \in T = \mathrm{cl}(I_C(x_0) \cap \widetilde{T}_2)$.

Если $I_C(x_0) \cap \mathrm{ri}\,\widetilde{T}_2 \ne \varnothing$, то по теореме 2.4.8[2,с.59] имеем, что $T = T_C(x_0) \cap \overline{T}_2 = \mathrm{cl}(I_C(x_0) \cap \widetilde{T}_2)$. Теорема доказана.

Отметим, что в теореме 5 можно считать, что

$$\widetilde{T}_2 \subset \{h \in X : F''(x_0)(h,h) \in \mathrm{Im}\,F'(x_0),\ \mathrm{Im}\,F'(x_0) + F''(x_0)(h, \mathrm{Ker}F'(x_0)) = Y\} \cup \{0\}.$$

Если $I_C(x_0) \cap \mathrm{ri}\,\widetilde{T}_2 \ne \varnothing$, то из теоремы 5 имеем, что точка нуль минимизирует выпуклую функцию $\sum_{i=0}^{m}\alpha_i\varphi_i(x) + \langle z^*, F'(x_0)x\rangle + \delta_{T_C(x_0)\cap\overline{T}_2}(x)$ в X. Так как $\overline{T}_2$ выпуклый конус, то

$$0 \in \partial\Big(\sum_{i=0}^{m}\alpha_i\varphi_i(x) + \langle z^*, F'(x_0)x\rangle + \delta_{T_C(x_0)\cap\overline{T}_2}(x)\Big)_{x=0} = \sum_{i=0}^{m}\alpha_i\partial\varphi_i(0) + F'(x_0)^*z^* + N_C(x_0) + (\overline{T}_2)^-.$$

Если $F'(x_0)(\overline{\mathrm{Lin}}\,\widetilde{T}_2) = \mathrm{Im}\,F'(x_0)$, то $F'(x_0)(\overline{\mathrm{Lin}}\,\widetilde{T}_2)$ замкнуто.

Замечание 1. Если X и Y конечномерные пространства, $C \subset X$ выпуклое множество $f_i : C \to R$, $i = 1,\ldots,k$, выпуклые непрерывные функции, $\Lambda : X \to Y$ непрерывный линейный оператор, то лемма 1 также верна. Если X и Y конечномерные пространства, то $\mathrm{Lin}\,\widetilde{T}_2$ и $F'(x_0)(\mathrm{Lin}\,\widetilde{T}_2)$ замкнутые множества.

Если $F''(x_0)(h_1,h_2) \in \mathrm{Im}\,F'(x_0)$ при $h_1, h_2 \in \widetilde{T}_2$, то легко проверяется, что $\widetilde{T}_2$ выпуклое множество.

Пусть $T_0 \subset \{h \in \mathrm{Ker}\,F'(x_0) : F''(x_0)(h,h) \in \mathrm{Im}\,F'(x_0),\ \mathrm{Im}\,G(x_0,h) = V\} \bigcup \{0\}$. Из теоремы о поправках [13, с.32] и теоремы 4 следует, что следующее следствие верно.

Следствие 3. Если X и Y банаховы пространства, x_0 -точка локального минимума в задаче (10), функции f_i имеют $\varphi_i - (o_i(1),\delta)$ верхнюю аппроксимацию в точке x_0 при $i \in I$, $\varphi_i : X \to R$ сублиней-

ные непрерывные функции при $i \in I$, $f_j(x_0) = 0$ при $j \in J$, отображение $F: X \to Y$ дважды дифференцируемо по Фреше в точке x_0, $\operatorname{Im} F'(x_0)$ замкнуто, T_0 выпуклый конус (либо $I_C(x_0) \bigcap T_0$ выпуклый конус), $C \subset X$, $I_C(x_0) \bigcap T_0 \neq \varnothing$, то существуют одновременно не равные нулю $\alpha_0 \geq 0$, $\alpha_1 \geq 0, \ldots, \alpha_m \geq 0$ такие, что $\sum_{i=0}^{m} \alpha_i \varphi_i(x) \geq 0$ при $x \in \operatorname{cl}(I_C(x_0) \bigcap T_0)$.

В следствие 3 можно считать , что

$$T_0 \subset \{h \in \operatorname{Ker} F'(x_0) : F''(x_0)(h,h) \in \operatorname{Im} F'(x_0),\ \operatorname{Im} F'(x_0) + F''(x_0)(h, \operatorname{Ker} F'(x_0)) = Y\} \cup \{0\}.$$

Если X и Y - пространства Фреше, $C \subset X$ - выпуклое множество, $f_i : C \to R$, $i = 0,1,\ldots,m$, выпуклые непрерывные функции, $\Lambda : X \to Y$ - линейный непрерывный оператор, $F(x) = Ax$, $Ax = \Lambda x + \bar{y}$, где $\bar{y} \in Y$, то рассмотрим задачу

$$f_0(x) \to \min \tag{11}$$

$$f_i(x) \leq 0, \quad i = 0,1,\ldots,m, \ A(x) = 0, \ x \in C. \tag{12}$$

Если $\varphi_0(x) = f_0(x) - f_0(x_0)$ и $\varphi_i(x) = f_i(x)$ при $i = 1,\ldots,m$, то из леммы 3 получаем обобщение теоремы Куна-Таккера для задачи выпуклого математического программирования.

Следствие 4. Если X и Y - пространства Фреше, x_0 - точка минимума в задаче (11),(12), $C \subset X$ - выпуклое множество, $f_i : C \to R$, $i = 0,1,\ldots,m$, выпуклые непрерывные функции, $\Lambda : X \to Y$ - линейный непрерывный оператор, $F(x) = Ax$, $Ax = \Lambda x + \bar{y}$, где $\bar{y} \in Y$, $\operatorname{Im} \Lambda = Y$ и система $f_1(x) < 0$, ..., $f_m(x) < 0$, $Ax = 0$ имеет решение на множестве C и существует точка $\bar{x} \in \operatorname{int} C$ такой, что $A\bar{x} = 0$, то существуют одновременно не равные нулю $\alpha_1 \geq 0, \ldots, \alpha_m \geq 0$ и $y^* \in Y^*$ такие, что $f_0(x) + \sum_{i=1}^{m} \alpha_i f_i(x) + \langle y^*, Ax \rangle \geq f_0(x_0) + \sum_{i=1}^{m} \alpha_i f_i(x_0) + \langle y^*, Ax_0 \rangle$ при $x \in C$ и $\alpha_i f_i(x_0) = 0$ при $i = 1,\ldots,m$.

Доказательство. По условию система $f_0(x) - f_0(x_0) < 0$ $f_1(x) < 0$, ..., $f_m(x) < 0$, $Ax = 0$ не имеет решения на множестве C, а система $f_1(x) < 0$, ..., $f_m(x) < 0$, $Ax = 0$ имеет решения на множестве C и существует точка $\bar{x} \in \operatorname{int} C$ такая, что $A\bar{x} = 0$, тогда по лемме 3 существуют одновременно не равные нулю $\alpha_1 \geq 0, \ldots, \alpha_m \geq 0$ и $y^* \in Y^*$ такие, что $f_0(x) - f_0(x_0) + \sum_{i=1}^{m} \alpha_i f_i(x) + \langle y^*, Ax \rangle \geq 0$ при $x \in C$. Если $x = x_0$, то отсюда следует, что $\sum_{i=1}^{m} \alpha_i f_i(x_0) + \langle y^*, Ax_0 \rangle \geq 0$. По условию имеем, что $\sum_{i=1}^{m} \alpha_i f_i(x_0) + \langle y^*, Ax_0 \rangle \leq 0$. Поэтому $\sum_{i=1}^{k} \alpha_i f_i(x_0) + \langle y^*, Ax_0 \rangle = 0$. Отсюда следует, что $\sum_{i=1}^{m} \alpha_i f_i(x_0) = 0$, т.е. $\alpha_i f_i(x_0) = 0$ при $i = 1,2,\ldots,k$.

Следствие доказано.

Из следствия 4 следует, что

$$0 \in \partial(f_0(x) + \sum_{i=1}^{m} \alpha_i f_i(x) + \langle y^*, Ax \rangle + \psi_C(x))_{|x=x_0} = \partial f_0(x_0) + \sum_{i=1}^{m} \alpha_i \partial f_i(x_0) + L^* y^* + N_C(x_0),$$

где $\psi_C(x)$ индикаторная функция множества C [см.12].

Ясно, что если система $f_1(x) < 0$, ..., $f_m(x) < 0$, $Ax = 0$ имеет решения на множестве $\operatorname{int} C$, то система $f_1(x) < 0$, ..., $f_m(x) < 0$, $Ax = 0$ имеет решения на множестве C и существует точка $\bar{x} \in \operatorname{int} C$ такая, что $A\bar{x} = 0$.

Пусть X və Y - пространства Фреше , $x_i^* : X \to R$, $i = 0,1,\ldots,m$, линейные непрерывные функции, $c_i \in R$, $\Lambda : X \to Y$ линейный непрерывный оператор, $Ax = \Lambda x + \bar{y}$, $\bar{y} \in Y$, $\operatorname{Im} \Lambda = Y$, то рассмотрим задачу

$$x_0^*(x) \to \min \tag{13}$$

$$x_i^*(x) + c_i \leq 0, \quad i = 1,\ldots,m, \ A(x) = 0 \tag{14}$$

Следствие 5. Если X и Y - пространства Фреше, x_0 - точка минимума в задаче (13),(14), $x_i^* : X \to R$, $i = 0,1,\ldots,m$, линейные непрерывные функции, $\Lambda : X \to Y$ - линейный непрерывный оператор, $Ax = \Lambda x + \bar{y}$, где $\bar{y} \in Y$, $\operatorname{Im} \Lambda = Y$, система $x_i^*(x) + c_i < 0$, $i = 1,\ldots,m$ и $A(x) = 0$ имеет

решения на X, то существуют одновременно не равные нулю $\lambda_1 \geq 0,...,\lambda_m \geq 0$ и $y^* \in Y^*$ такие, что

$$x_0^*(x) + \sum_{i=1}^{m} \lambda_i (x_i^*(x) + c_i) + \langle y^*, Ax \rangle \geq x_0^*(x_0) = x_0^*(x_0) + \sum_{i=1}^{m} \lambda_i (x_i^*(x_0) + c_i) + \langle y^*, Ax_0 \rangle$$

при $x \in X$ и $\lambda_i(x_i^*(x_0) + c_i) = 0$ при $i = 1,2,\ldots,m$.

Из следствия 5 следует, что

$$(x_0^*(x) + \sum_{i=1}^{m} \lambda_i (x_i^*(x) + c_i) + \langle y^*, Ax \rangle)' = x_0^* + \sum_{i=1}^{m} \lambda_i x_i^* + \Lambda y^* = 0,$$

где $\lambda_i(x_i^*(x_0) + c_i) = 0$ при $i = 1,2,\ldots,m$.

Пусть X вещественное банахово пространство, $g_i : X \to R$ произвольные функции, где $i = 1,\ldots,k$. Обозначим $S = \{x \in C : g_i(x) = 0, i = 1,\ldots,k\}$, $d_S(x) = \inf\{\|y - x\| : y \in S\}$.

Вектор функции $(g_1(x),\ldots,g_k(x))$ будем называть регулярным в точке $x_0 \in S$ относительно множества C, если существует такое число $r > 0$, что $d_S(x) \leq r\sum_{i=1}^{k} |g_i(x)|$ при $x \in C$, $\|x - x_0)\| \leq \delta$.

Положим $f(x) = \max\{f_0(x) - f_0(x_0), f_1(x),\ldots,f_n(x)\}$, см. также теорему 1.5.4 [8].

Теорема 6. Пусть X банахово пространство, x_0 является минимумом функции f_0 на множестве $\{x \in C : f_i(x) \leq 0, i = \overline{1,n}, g_j(x) = 0, j = \overline{1,k}\}$, где $f_i : X \to R$, $i = 0,1,\ldots,n$, $g_j : X \to R$, $j = 1,\ldots,k$, функции f_i, $i = 0,1,\ldots,n$, удовлетворяют липшицеву условию в $B(x_0, \delta)$ с постоянной K_i, вектор функция $(g_1(x),\ldots,g_k(x))$ регулярна в точке x_0 относительно множества C, $g_j : X \to R$ удовлетворяет липшицеву условию в $B(x_0, \delta)$ с постоянной L_j при $j = 1,\ldots,k$ и $C \subset B(x_0, \delta)$. Тогда для любого $\mu \geq \max\{Kr, K + KLr\}$ функция $G_\lambda(x) = f(x) + \mu\sum_{j=1}^{k} |g_j(x)| + \mu d_C(x)$ достигает минимума на множестве $B(x_0, \delta)$ в точке x_0 и если C замкнуто и $\mu > \max\{Kr, K + KLr\}$, то любая точка минимизирующая $G_\mu(x)$ на множестве $B(x_0, \delta)$ принадлежит C, где $f(x) = \max\{f_0(x) - f_0(x_0), f_1(x),\ldots,f_n(x)\}$, r коэффициент регулярности, $K = \max\{K_0, K_1,\ldots,K_n\}$ и $L = L_1 + \ldots + L_k$.

Доказательство. Так как x_0 является минимумом функции f_0 на множестве $\{x \in C : f_i(x) \leq 0, i = \overline{1,n}, g_j(x) = 0, j = \overline{1,k}\}$, то x_0 также минимизирует функции f на множестве $S = \{x \in C : g_j(x) = 0, j = 1,\ldots,k\}$. Если функции f_0 и f_i $i = \overline{1,n}$, удовлетворяют липшицеву условию в $B(x_0, \delta)$ с постоянной K_i, то имеем, что f удовлетворяет липшицеву условию в $B(x_0, \delta)$ с постоянной $K = \max\{K_0, K_1,\ldots,K_n\}$. Применяя теоремы 1 на пары множеств $S = \{x \in C : g_j(x) = 0, j = 1,\ldots,k\}$ и C имеем, что для любого $\lambda \geq K$ функция $\overline{G}_\lambda(x) = f(x) + \lambda d_S(x)$ достигает минимума на C в точке x_0 и если $\lambda > K$ и S замкнуто, то любая точка минимизирующая $G_\lambda(x)$ на множестве C принадлежит S.

Так как вектор функция $(g_1(x),\ldots,g_k(x))$ регулярна в точке $x_0 \in S$ относительно множества C, то существует такое число $r > 0$, что $d_S(x) \leq r\sum_{j=1}^{k} |g_j(x)|$ при $x \in C$. Поэтому функция $\widetilde{G}_K(x) = f(x) + Kr\sum_{i=1}^{k} |g_i(x)|$ достигает минимума на C в точке x_0.

Отметим, что функция $\sum_{j=1}^{k} |g_j(x)|$ удовлетворяет липшицеву условию в $B(x_0, \delta)$ спостоянной $L = L_1 + \cdots + L_k$. Так как функция $\widetilde{G}_K(x) = f(x) + Kr\sum_{j=1}^{k} |g_j(x)|$ в $B(x_0, \delta)$ удовлетворяет липшицеву условию с постоянной $K + KLr$, то функция $f(x) + Kr\sum_{i=1}^{k} |g_i(x)| + (K + KLr)d_C(x)$ достигает минимума на $B(x_0, \delta)$ в точке x_0. Поэтому для любого $\mu \geq \max\{Kr, K + KLr\}$ функция $G_\mu(x) = f(x) + \mu\sum_{i=1}^{k} |g_i(x)| + \mu d_C(x)$ достигает минимума на $B(x_0, \delta)$ в точке x_0.

Если C замкнуто и $\mu > \max\{Kr, K + KLr\}$, то из следствия 1 следует, что любая точка минимизирующая $G_\mu(x)$ на множестве $B(x_0, \delta)$ принадлежит C. Теорема доказана.

Обозначим $I = \{1,\dots,n\}$, $I(x) = \{i \in I : f_i(x) = g(x)\}$, $g(x) = \max\limits_{i\in I} f_i(x)$.

Лемма 4. Если функции $f_i : X \to R_{+\infty}$ удовлетворяет локальному липшицеву условию в $\operatorname{int}\operatorname{dom} f_i$ при $i \in I$ и $x \in \bigcap\limits_{i=1}^{n} \operatorname{int}\operatorname{dom} f_i$, то $g^+(x;\upsilon) = \max\limits_{i\in I(x)} f_i^+(x;\upsilon)$ при $\upsilon \in X$.

Доказательство. Если $i \in I(x)$, то $\dfrac{f_i(x+h\upsilon) - f_i(x)}{h} \le \dfrac{g(x+h\upsilon) - g(x)}{h}$. Отсюда следует, что

$$\limsup_{h\downarrow 0} \frac{f_i(x+h\upsilon) - f_i(x)}{h} \le \limsup_{h\downarrow 0} \frac{g(x+h\upsilon) - g(x)}{h}$$

при $i \in I(x)$. Поэтому $f_i^+(x;\upsilon) \le g^+(x;\upsilon)$ при $\upsilon \in X$ и $i \in I(x)$. Тогда получим, что $\sup\limits_{i\in I(x)} f_i^+(x;\upsilon) \le g^+(x;\upsilon)$ при $\upsilon \in X$. Докажем обратное неравенство.

Покажем, что существует $\alpha_1 > 0$ такое, что $I(y) \subset I(x)$ при $\|y - x\| \le \alpha_1$. Если $I(x) = I$, то очевидно. Если $I(x) \ne I$, то положим $a = g(x) - \max\limits_{i\notin I(x)} f_i(x) > 0$, $\varepsilon = \dfrac{a}{3}$. Так как функции f_i непрерывны в точке x, то существует число $\alpha_1 > 0$ такое, что $|f_i(y) - f_i(x)| \le \varepsilon$ при $\|y - x\| \le \alpha_1$ и $i \in I$. Тогда имеем, что $|g(y) - g(x)| \le \varepsilon$ при $\|y - x\| \le \alpha_1$. Если $\|y - x\| \le \alpha_1$ и $j \in I(y)$, то

$$f_j(x) \ge f_j(y) - \varepsilon = g(y) - \varepsilon \ge g(x) - 2\varepsilon = a + \max_{i\notin I(x)} f_i(x) - 2\varepsilon > \max_{i\notin I(x)} f_i(x).$$

Поэтому $j \in I(x)$. Тогда получим, что $I(y) \subset I(x)$ при $\|y - x\| \le \alpha_1$.

Положив $\beta \le \dfrac{\alpha_1}{2\|\upsilon\|}$ и $\theta \le \beta$ имеем, что

$$\frac{g(x+\theta\upsilon) - g(x)}{\theta} \le \max_{i\in I(x+\theta\upsilon)} \frac{f_i(x+\theta\upsilon) - f_i(x)}{\theta} \le \max_{i\in I(x)} \frac{f_i(x+\theta\upsilon) - f_i(x)}{\theta}. \tag{15}$$

По определению $f_i^+(x;\upsilon)$ существует число $\beta_i > 0$ такое, что

$$\sup_{0<\theta\le\beta_i} \frac{f_i(x+\theta\upsilon) - f_i(x)}{\theta} \le f_i^+(x,\upsilon) + \varepsilon \tag{16}$$

при $\theta \le \beta_i$. Обозначив $\min\limits_{i\in I(x)} \beta_i = \beta$ из (15) и (16) имеем, что

$$\sup_{0<\theta\le\beta} \frac{g(x+\theta\upsilon) - g(x)}{\theta} \le \sup_{0<\theta\le\beta} \max_{i\in I(x)} \frac{f_i(x+\theta\upsilon) - f_i(x)}{\theta} \le \max_{i\in I(x)} f_i^+(x,\upsilon) + \varepsilon .$$

Отсюда следует, что $g^+(x;\upsilon) \le \max\limits_{i\in I(x)} f_i^+(x;\upsilon)$ при $\upsilon \in X$.

Поэтому получим, что $g^+(x;\upsilon) = \max\limits_{i\in I(x)} f_i^+(x;\upsilon)$ при $\upsilon \in X$. Лемма доказана.

Если положить $f(x) = \max\{r_0(f_0(x) - f_0(x_0)) + \sum\limits_{i=1}^{n} r_i f_i(x) : r_i \ge 0,\ i = 0,1,\dots,n,\ \sum\limits_{i=0}^{n} r_i = 1\}$,

то теорема 6 также остается справедливой.

В теореме 6 множество C можно заменить множеством $C \cap B(x_0, \delta)$.

Из теоремы 6 следует, что если $\mu \ge \max\{Kr, K + KLr\}$, то $G_\mu^+(x_0;x) \ge 0$ при $x \in X$. Поэтому $0 \in \partial^+ G_\mu(x_0)$. Если выполняются условия теоремы 6, то из леммы 4 следует, что

$$G_\mu^+(x_0;x) \le \max_{i\in P(x_0)} f_i^+(x_0;x) + \mu \sum_{j=1}^{k} \max\{g_j^+(x_0;x), (-g_j)^+(x_0;x)\} + \mu d_C^+(x_0;x)$$

при $x \in X$, где $P = \{1,\dots,n\}$, $P(x_0) = \{i \in P : f_i(x_0) = 0\} \bigcup \{0\}$.

Пусть функции $f_i : X \to R$, $g_j : X \to R$ квазисубдифференцируемы в точке x_0 при $i = 1,\dots,n$, $j = 1,\dots,k$, т.е. $f_i'(x_0;x) = p_i(x) + q_i(x)$, $g_j'(x_0;x) = \overline{p}_j(x) + \overline{q}_j(x)$, где $p_i(x)$, $-q_i(x)$, $\overline{p}_j(x)$, $-\overline{q}_j(x)$ непрерывные сублинейные функции, C выпуклое множество. Ясно, что $(-g_j)'(x_0;x) = -g_j'(x_0;x) = -\overline{p}_j(x) - \overline{q}_j(x)$ при $x \in X$. Поэтому

$$G'_\mu(x_0;x)=\max_{i\in P(x_0)} f'_i(x_0;x)+\mu\sum_{j=1}^{k}\left|g'_j(x_0;x)\right|+\mu d'_C(x_0;x)$$

при $x\in X$. Отсюда следует, что

$$G'_\mu(x_0;x)=\max_{i\in P(x_0)}(p_i(x)+q_i(x))+\mu\sum_{j=1}^{k}\left|\overline{p}_j(x)+\overline{q}_j(x)\right|+\mu d'_C(x_0;x)$$

при $x\in X$. Ясно, что

$$f'_i(x_0;x)=p_i(x)+q_i(x)=\max_{x^*\in\underline{\partial}p_i}\langle x^*,x\rangle+\min_{y^*\in\partial q_i}\langle y^*,x\rangle\le\max_{x^*\in\underline{\partial}p_i}\langle x^*,x\rangle+\langle y_i^*,x\rangle$$

при $x\in X$, где $y_i^*\in\overline{\partial}q_i$. Также имеем, что

$$\left|g'_j(x_0;x)\right|=\left|\overline{p}_j(x)+\overline{q}_j(x)\right|=\max\{\overline{p}_j(x)+\overline{q}_j(x),-\overline{p}_j(x)-\overline{q}_j(x)\}=$$

$$=\max\{\max_{x^*\in\underline{\partial}\overline{p}_j}\langle x^*,x\rangle+\min_{y^*\in\partial\overline{q}_j}\langle y^*,x\rangle,-\max_{x^*\in\underline{\partial}\overline{p}_j}\langle x^*,x\rangle-\min_{y^*\in\partial\overline{q}_j}\langle y^*,x\rangle\}=$$

$$=\max\{\max_{x^*\in\underline{\partial}\overline{p}_j}\langle x^*,x\rangle+\min_{y^*\in\partial\overline{q}_j}\langle y^*,x\rangle,\min_{z^*\in-\underline{\partial}\overline{p}_j}\langle z^*,x\rangle+\max_{\upsilon^*\in-\overline{\partial}\overline{q}_j}\langle\upsilon^*,x\rangle\}\le$$

$$\le\max\{\max_{x^*\in\underline{\partial}\overline{p}_j}\langle x^*,x\rangle+\langle z_j^*,x\rangle,\max_{\upsilon^*\in-\overline{\partial}\overline{q}_j}\langle\upsilon^*,x\rangle-\langle\overline{z}_j^*,x\rangle\}$$

при $x\in X$, $z_j^*\in\overline{\partial}\overline{q}_j$, $\overline{z}_j^*\in\underline{\partial}\overline{p}_j$. Поэтому

$$G'_\mu(x_0;x)\le\max_{i\in P(x_0)}(\max_{x^*\in\underline{\partial}p_i}\langle x^*,x\rangle+\langle y_i^*,x\rangle)+$$

$$+\mu\sum_{j=1}^{k}\max\{\max_{x^*\in\underline{\partial}\overline{p}_j}\langle x^*,x\rangle+\langle z_j^*,x\rangle,\max_{\upsilon^*\in-\overline{\partial}\overline{q}_j}\langle\upsilon^*,x\rangle-\langle\overline{z}_j^*,x\rangle\}+\mu d'_C(x_0;x)$$

при $x\in X$, $y_i^*\in\overline{\partial}q_i$, $z_j^*\in\overline{\partial}\overline{q}_j$, $\overline{z}_j^*\in\underline{\partial}\overline{p}_j$.

Отсюда следует, что

$$\partial G_\mu(x_0)\subset\operatorname{co}\bigcup_{i\in P(x_0)}(\underline{\partial}p_i+y_i^*)+\mu\sum_{j=1}^{k}\operatorname{co}\{(\underline{\partial}\overline{p}_j+z_j^*)\bigcup(-\overline{\partial}\overline{q}_j-\overline{z}_j^*)\}+\mu\partial d_C(x_0),$$

где $y_i^*\in\overline{\partial}q_i$, $z_j^*\in\overline{\partial}\overline{q}_j$, $\overline{z}_j^*\in\underline{\partial}\overline{p}_j$.

Таким образом, получим, что справедлива следующая теорема.

Теорема 7. Пусть X банахово пространство, x_0 является минимумом функции f_0 на множестве $\{x\in C: f_i(x)\le 0,\ i=\overline{1,n},\ g_j(x)=0,\ j=\overline{1,k}\}$, где $f_i: X\to R$, $i=0,1,\dots,n$, $g_j: X\to R$, $j=1,\dots,k$, выполняются условия теоремы 6, функции $f_i: X\to R$, $g_j: X\to R$ квазисубдифференцируемы в точке x_0 при $i=1,\dots,n$, $j=1,\dots,k$, т.е. $f'_i(x_0;x)=p_i(x)+q_i(x)$, $g'_j(x_0;x)=\overline{p}_j(x)+\overline{q}_j(x)$, где $p_i(x)$, $-q_i(x)$, $\overline{p}_j(x)$, $-\overline{q}_j(x)$ непрерывные сублинейные функции, C выпуклое множество. Тогда

$$0\in\partial G_\mu(x_0)\subset\operatorname{co}\bigcup_{i\in P(x_0)}(\underline{\partial}p_i+y_i^*)+\mu\sum_{j=1}^{k}\operatorname{co}\{(\underline{\partial}\overline{p}_j+z_j^*)\bigcup(-\overline{\partial}\overline{q}_j-\overline{z}_j^*)\}+\mu\partial d_C(x_0),$$

где $y_i^*\in\overline{\partial}q_i$, $z_j^*\in\overline{\partial}\overline{q}_j$, $\overline{z}_j^*\in\underline{\partial}\overline{p}_j$, $\mu\ge\max\{Kr,K+KLr\}$.

Отметим, что из включения $\partial q\subset\partial p$ следует, что $0\in\partial p-z^*$ при $z^*\in\partial q$, где $\partial q\ne\varnothing$.

Функция $f: X\times Y\to R_{+\infty}$ называется раздельно 2-липшицевой с постоянной L в точке (x_0,y_0), если существует $\delta>0$ такое, что

$$\left|f(x_0+x,y_0+y)-f(x_0+x,y_0)-f(x_0,y_0+y)+f(x_0,y_0)\right|\le L\|x\|\|y\|$$

при $x\in\delta B_X$, $y\in\delta B_Y$.

Функция $f: X\times Y\to R_{+\infty}$ называется раздельно 2-липшицевой с постоянной L в окрестности точки (x_0,y_0), если существует $\delta>0$ такое, чт $\left|f(z_1+x,z_2+y)-f(z_1+x,z_2)-f(z_1,z_2+y)+f(z_1,z_2)\right|\le L\|x\|\cdot\|y\|$ при $z_1\in x_0+\delta B_X$, $z_2\in y_0+\delta B_Y$, $x\in\delta B_X$, $y\in\delta B_Y$.

Рассмотрим задачу

$$f_0(x,y)\to\min,\quad (x,y)\in\{(x,y)\in X\times Y: f_i(x,y)\le 0,\ i=1,\dots,m,\ F(x,y)=0,\ (x,y)\in C\}. \tag{17}$$

Пусть $f: X\times Y\to R$. Положим

$$f^0((x_0,y_0);(x,y)) = \overline{\lim_{\substack{z_1\to x_0\\ z_2\to y_0\\ \lambda\downarrow 0}}} \frac{1}{\lambda}\big(f(z_1+\lambda x, z_2+\lambda y) - f(z_1,z_2)\big).$$

Из леммы 2 и теоремы 2 следует следующее следствие.

Следствие 6. Если X и Y банаховы пространства, (x_0,y_0) -точка локального минимума в задаче (17), бивыпуклые функции f_i непрерывны в точке (x_0,y_0) и удовлетворяют раздельно 2-липшицеву условию в окрестности точки (x_0,y_0), где $i\in I$, $f_j(x_0,y_0)=0$ при $j\in J$, оператор $F: X\times Y\to Z$ строго дифференцируем в точке (x_0,y_0), $F'(x_0,y_0)(X\times Y)=Z$, $C\subset X\times Y$, $I_C(x_0,y_0)\neq\varnothing$, то существуют одновременно не равные нулю

$\alpha_0\geq 0,\ \alpha_1\geq 0,\ldots,\alpha_m\geq 0$ и $z^*\in Z^*$ такие, что

$$\sum_{i=0}^{m}\alpha_i(f'((x_0,y_0);(x,0)) + f'((x_0,y_0);(0,y)) + \langle z^*, F'(x_0,y_0)(x,y)\rangle \geq 0$$

при $(x,y)\in T_C(x_0,y_0)$.

Доказательство. При условии следствия 4 из леммы 4.2[14] следует, что

$$f^0((x_0,y_0);(x,y)) = f'((x_0,y_0);(x,y)) = f'((x_0,y_0);(x,0)) + f'((x_0,y_0);(0,y))$$

при $(x,y)\in X\times Y$. Тогда из теоремы 3 следует справедливость следствия 6.

Из следствия 6 следует, что $0\in\sum_{i=0}^{m}\alpha_i(\partial_x f(x_0,y_0),\partial_y f(x_0,y_0)) + F'(x_0,y_0)^* z^* + N_C(x_0,y_0)$.

Через $B(X\times Y,R)$ обозначим множество всех билинейных непрерывных функций из $X\times Y$ в R.

Лемма 5. Если $\varphi\in A(X\times Y)$, т.е. $\varphi(x,y)=\sup_{t\in T}(x_t^*(x,y)+v_t^*(x)+y_t^*(y)+c_t)$, где $x_t^*\in B(X\times Y,R)$, $v_t^*\in X^*$, $y_t^*\in Y^*$, $c_t\in R$ и существуют числа L_0, L_1, L_2 и L_3 такие, что $|x_t^*(x,y)|\leq L_0\|x\|\|y\|$, $|v_t^*(x)|\leq L_1\|x\|$, $|y_t^*(y)|\leq L_2\|y\|$ и $|c_t|\leq L_3$ при $(x,y)\in X\times Y$ и $t\in T$, то $\varphi(x,y)$ непрерывная функция.

Доказательство. Если $(x,y)\in X\times Y$, $(x_1,y_1)\in X\times Y$, то

$$\varphi(x,y)-\varphi(x_1,y_1) = \sup_{t\in T}(x_t^*(x,y)+v_t^*(x)+y_t^*(y)+c_t) - \sup_{t\in T}(x_t^*(x_1,y_1)+v_t^*(x_1)+y_t^*(y_1)+c_t)\leq$$

$$\leq \sup_{t\in T}(x_t^*(x,y)+v_t^*(x)+y_t^*(y)) - x_t^*(x_1,y_1) - v_t^*(x_1) - y_t^*(y_1))\leq$$

$$\leq \sup_{t\in T}(x_t^*(x,y)-x_t^*(x_1,y)+x_t^*(x_1,y)-x_t^*(x_1,y_1)+v_t^*(x)+y_t^*(y)-v_t^*(x_1)-y_t^*(y_1))\leq$$

$$\leq L_0(\|x-x_1\|\|y\|+\|x_1\|\|y-y_1\|)+L_1\|x-x_1\|+L_2\|y-y_1\|)\leq (L_0(\|y\|+\|x_1\|)+L_1+L_2)(\|x-x_1\|+\|y-y_1\|).$$

Аналогично имеем, что

$$\varphi(x,y)-\varphi(x_1,y_1) = \sup_{t\in T}(x_t^*(x,y)+v_t^*(x)+y_t^*(y)+c_t) - \sup_{t\in T}(x_t^*(x_1,y_1)+v_t^*(x_1)+y_t^*(y_1)+c_t)\geq$$

$$\geq \inf_{t\in T}(x_t^*(x,y)+v_t^*(x)+y_t^*(y)) - x_t^*(x_1,y_1) - v_t^*(x_1) - y_t^*(y_1))\leq$$

$$\geq \inf_{t\in T}(x_t^*(x,y)-x_t^*(x_1,y)+x_t^*(x_1,y)-x_t^*(x_1,y_1)+v_t^*(x)+y_t^*(y)-v_t^*(x_1)-y_t^*(y_1))\leq$$

$$\geq -L_0(\|x-x_1\|\|y\|+\|x_1\|\|y-y_1\|)-L_1\|x-x_1\|-L_2\|y-y_1\|)\leq$$

$$\geq -(L_0(\|y\|+\|x_1\|)+L_1+L_2)(\|x-x_1\|+\|y-y_1\|).$$

Поэтому $|\varphi(x,y)-\varphi(x_1,y_1)|\leq (L_0(\|y\|+\|x_1\|)+L_1+L_2)(\|x-x_1\|+\|y-y_1\|)$ при $(x,y)\in X\times Y$. Отсюда имеем, что $\varphi(x,y)$ непрерывная функция. Лемма доказана.

Если $f\in A(X\times Y)$, т.е. $f(x,y)=\sup_{t\in T}(x_t^*(x,y)+v_t^*(x)+y_t^*(y)+c_t)$, где $x_t^*\in B(X\times Y,R)$, $v_t^*\in X^*$, $y_t^*\in Y^*$, $c_t\in R$ и существуют положительные числа L_0, L_1, L_2 и L_3 такие, что $|x_t^*(x,y)|\leq L_0\|x\|\|y\|$, $|z_t^*(x)|\leq L_1\|x\|$, $|y_t^*(y)|\leq L_2\|y\|$ и $|c_t|\leq L_3$ при $(x,y)\in X\times Y$ и $t\in T$, то $\varphi(x,y)$ непрерывная функция. Кроме того имеем

$$f^+((x_0,y_0);(x,y)) = \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}\big(f(x_0+\lambda x, y_0+\lambda y) - f(x_0,y_0)\big) = \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}(\sup_{t\in T}(x_t^*(x_0+\lambda x, y_0+\lambda y) + v_t^*(x_0+\lambda x) +$$

$$+ y_t^*(y_0+\lambda y) + c_t) - \sup_{t\in T}(x_t^*(x_0,y_0) + v_t^*(x_0) + y_t^*(y_0) + c_t)) \le$$

$$\le \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}(\sup_{t\in T}(x_t^*(x_0+\lambda x, y_0+\lambda y) + v_t^*(x_0+\lambda x) + y_t^*(y_0+\lambda y)) - (x_t^*(x_0,y_0) + v_t^*(x_0) + y_t^*(y_0))) =$$

$$= \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}(\sup_{t\in T}(x_t^*(x_0+\lambda x, y_0+\lambda y) + v_t^*(x_0+\lambda x) + y_t^*(y_0+\lambda y)) - (x_t^*(x_0,y_0) + v_t^*(x_0) + y_t^*(y_0))) =$$

$$= \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}(\sup_{t\in T}(x_t^*(\lambda x,\lambda y) + x_t^*(x_0,\lambda y) + x_t^*(\lambda x, y_0) + v_t^*(\lambda x) + y_t^*(\lambda y)) =$$

$$= \overline{\lim_{\lambda\downarrow 0}}(\sup_{t\in T}(\lambda x_t^*(x,y) + x_t^*(x_0,y) + x_t^*(x,y_0) + v_t^*(x) + y_t^*(y)).$$

Так как $\left|x_t^*(x,y)\right| \le L_0\|x\|\|y\|$ при $t\in T$, то отсюда следует, что

$$f^+((x_0,y_0);(x,y)) \le \sup_{t\in T}(x_t^*(x_0,y) + x_t^*(x,y_0) + v_t^*(x) + y_t^*(y))$$

при $(x,y)\in X\times Y$.

Лемма 6. Пусть I конечное множество, $f_i : X\times Y \to R,\ i\in I,$ непрерывные функции в точке (x_0,y_0), существуют $\delta>0$ и $L>0$ такие, что

$$f_i(x_0+x, y_0+y) - f_i(x_0+x, y_0) - f_i(x_0, y_0+y) + f(x_0,y_0) \le L\|x\|\cdot\|y\|$$

при $x\in\delta B_X,\ y\in\delta B_Y,\ f(x,y) = \max\limits_{i\in I} f_i(x,y)$. Тогда существует $\delta_0>0$ такое, что

$$f(x_0+x, y_0+y) - f(x_0+x, y_0) - f(x_0, y_0+y) + f(x_0,y_0) \le L\|x\|\cdot\|y\|$$

при $x\in\delta_0 B_X,\ y\in\delta_0 B_Y$.

Доказательство. Обозначим $I(x,y) = \{i\in I : f(x,y) = f_i(x,y)\}$. Покажем, что существует $\delta_1>0$ такое, что $I(x,y)\subset I(x_0,y_0)$ при $x\in x_0+\delta_1 B_X,\ y\in y_0+\delta_1 B_Y$. Случай $I(x_0,y_0) = I$ тривиален. Пусть $I(x_0,y_0)\ne I$. Положим $b = f(x_0,y_0) - \max\limits_{i\in I/I(x_0,y_0)} f_i(x_0,y_0) > 0$ и $\varepsilon = \frac{b}{3}$. Тогда существует $\delta_1>0$ такое, что для каждого $i\in I$ выполнено $\left|f_i(x,y) - f_i(x_0,y_0)\right| \le \varepsilon$ при $x\in x_0+\delta_1 B_X,\ y\in y_0+\delta_1 B_Y$. Легко можно проверить, что $\left|f(x,y) - f(x_0,y_0)\right| \le \varepsilon$ при $x\in x_0+\delta_1 B_X,\ y\in y_0+\delta_1 B_Y$. Если $j\in I(x,y)$, то

$$f_j(x_0,y_0) \ge f_j(x,y) - \varepsilon = f(x,y) - \varepsilon \ge f(x_0,y_0) - 2\varepsilon =$$

$$= \max_{i\notin I(x_0,y_0)} f_i(x_0,y_0) + b - 2\varepsilon > \max_{i\notin I(x_0,y_0)} f_i(x_0,y_0).$$

Поэтому $j\in I(x_0,y_0)$, т.е. $I(x,y)\subset I(x_0,y_0)$. Обозначим $\delta_0 = \min\{\delta,\delta_1\}$. Если $\|u\|\le\delta_0,\ \|\upsilon\|\le\delta_0$, то

$$f(x_0+u, y_0+\upsilon) - f(x_0+u, y_0) - f(x_0, y_0+\upsilon) + f(x_0,y_0) \le$$

$$\le \max_{i\in I(x_0,y_0)}(f_i(x_0+u, y_0+\upsilon) + f_i(x_0,y_0)) - \max_{i\in I(x_0,y_0)} f_i(x_0+u, y_0) -$$

$$- \max_{i\in I(x_0,y_0)} f_i(x_0, y_0+\upsilon) \le \max_{i\in I(x_0,y_0)}(f_i(x_0+u, y_0+\upsilon) - f_i(x_0+u, y_0) -$$

$$- f_i(x_0, y_0+\upsilon) + f_i(x_0,y_0)) \le L\|u\|\|\upsilon\|.$$

Лемма доказана.

Лемма 7. Пусть I конечное множество, $f_i : X\times Y\to R,\ i\in I,$ непрерывные функции в точке (x_0,y_0), f_i раздельно 2-липшицевые функции с постоянной L_i в ν_i-окрестности точки (x_0,y_0), $f(x,y) = \max\limits_{i\in I} f_i(x,y)$, существует $\delta_1>0$ такое, что $I(x_1,y_1)\cap I(x_2,y_2)\ne\emptyset$ при $x_1,x_2\in x_0+\delta_1 B_X,\ y_1,y_2\in y_0+\delta_1 B_Y$, где $I(x,y) = \{i\in I : f(x,y) = f_i(x,y)\}$. Тогда f раздельно 2-липшицевая функция в окрестности (x_0,y_0).

Доказательство. Аналогично доказательству леммы 6 проверяется, что существует $\delta_2>0$ такое, что $I(x,y)\subset I(x_0,y_0)$ при $x\in x_0+\delta_2 B_X,\ y\in y_0+\delta_2 B_Y$. Положим $\delta_0 = \min\{\delta_1,\delta_2\}$,

$\delta = \min\left\{\frac{\delta_0}{2}, b_i,\ i\in I\right\}$. Если $z_1\in x_0+\delta B_X,\ z_2\in y_0+\delta B_Y,\ \|x\|\le\delta,\ \|y\|\le\delta$, то

$$f(z_1+x,z_2+y)-f(z_1+x,z_2)-f(z_1,z_2+y)+f(z_1,z_2)=\max_{i\in I(z_1+x,z_2+y)} f_i(z_1+x,z_2+y)-$$

$$-\max_{i\in I} f_i(z_1+x,z_2)-\max_{i\in I} f_i(z_1,z_2+y)+\max_{i\in I(z_1,z_2)} f_i(z_1,z_2)\le$$

$$\le \max_{i\in I(z_1,z_2)\cap I(z_1+x,z_2+y)}(f_i(z_1+x,z_2+y)+f_i(z_1,z_2))-\max_{i\in I(x_0,y_0)}(f_i(z_1+x,z_2)+$$

$$+f_i(z_1,z_2+y))=\max_{i\in I(x_0,y_0)}(f_i(z_i+x,z_2+y)+f_i(z_1,z_2))-$$

$$-\max_{i\in I(x_0,y_0)}(f_i(z_1+x,z_2)+f_i(z_1,z_2+y))\le \max_{i\in I(x_0,y_0)}(f_i(z_1+x,z_2+y)-f_i(z_1+x,z_2)-$$

$$-f_i(z_1,z_2+y)+f_i(z_1,z_2))\le \max_{i\in I(x_0,y_0)} L_i\|x\|\|y\|.$$

Аналогично имеем, что

$$f(z_1+x,z_2+y)-f(z_1+x,z_2)-f(z_1,z_2+y)+f(z_1,z_2)=\max_{i\in I(x_0,y_0)} f_i(z_1+x,z_2+y)+$$

$$+\min_{i\in I(z_1+x,z_2)\cap I(z_1,z_2+y)}(-f_i(z_1+x,z_2)-f_i(z_1,z_2+y)+\max_{i\in I(x_0,y_0)} f_i(z_1,z_2)\ge$$

$$\ge \min_{i\in I(x_0,y_0)}(f_i(z_1+x,z_2+y)-f_i(z_1+x,z_2)-f_i(z_1,z_2+y)+f_i(z_1,z_2))\ge$$

$$\ge \min_{i\in I(x_0,y_0)} -L_i\|x\|\|y\|=-(\max_{i\in I(x_0,y_0)} L_i)\|x\|\cdot\|y\|.$$

при $z_1\in x_0+\delta B_X$, $z_2\in y_0+\delta B_Y, x\in\delta B_X, y\in\delta B_Y$. Тогда получим

$$\left|f(z_1+x,z_2+y)-f(z_1+x,z_2)-f(z_1,z_2+y)+f(z_1,z_2)\right|\le L\|x\|\cdot\|y\|$$

при $z_1\in x_0+\delta B_X$, $z_2\in y_0+\delta B_Y, x\in\delta B_X, y\in\delta B_Y$, где $L=\max\{L_i : i\in I(x_0,y_0)\}$. Лемма доказана.

Если в лемме 7 предположить, что f_i раздельно 2-липшицевые функции в точке (x_0,y_0), то аналогично лемме 7 проверяется, что f также раздельно 2-липшицевая функция в точке (x_0,y_0).

Пусть I конечное множество, $f_i(x,y)=x_i^*(x,y)+v_i^*(x)+y_i^*(y)+c_i$ при $i\in I$.

$$f_i(x_0+x,y_0+y)-f_i(x_0+x,y_0)-f_i(x_0,y_0+y)+f(x_0,y_0)=x_i^*(x_0+x,y_0+y)+v_i^*(x_0+x)+$$

$$+y_i^*(y_0+y)+c_i-x_i^*(x_0+x,y_0)-v_i^*(x_0+x)-y_i^*(y_0)-c_i-x_i^*(x_0,y_0+y)-v_i^*(x_0)-y_i^*(y_0+y)-$$

$$-c_i+x_i^*(x_0,y_0)+v_i^*(x_0)+y_i^*(y_0)+c_i=x_i^*(x,y)$$

при $x\in X$, $y\in Y$. Так как существует $L_i>0$ такое, что $\left|x_i^*(x,y)\right|\le L_i\|x\|\cdot\|y\|$ при $x\in X$, $y\in Y$. Поэтому $\left|f_i(x_0+x,y_0+y)-f_i(x_0+x,y_0)-f_i(x_0,y_0+y)+f(x_0,y_0)\right|=\left|x_i^*(x,y)\right|\le L_i\|x\|\cdot\|y\|$ при $x\in X$, $y\in Y$.

Из леммы 7 следует следующее следствие.

Следствие 7. Пусть I конечное множество, $f_i(x,y)=x_i^*(x,y)+v_i^*(x)+y_i^*(y)+c_i$ при $i\in I$, $f(x,y)=\max_{i\in I} f_i(x,y)$. Тогда существует $\delta_0>0$ и L такие, что

$$f(x_0+x,y_0+y)-f_i(x_0+x,y_0)-f(x_0,y_0+y)+f(x_0,y_0)\le L\|x\|\cdot\|y\|$$

при $x\in\delta_0 B_X$, $y\in\delta_0 B_Y$.

Следствие 8. Пусть I конечное множество, $f_i(x,y)=x_i^*(x,y)+v_i^*(x)+y_i^*(y)+c_i$ при $i\in I$, $f(x,y)=\max_{i\in I} f_i(x,y)$, существует $\delta_1>0$ такое, что $I(x_1,y_1)\cap I(x_2,y_2)\ne\emptyset$ при $x_1,x_2\in x_0+\delta_1 B_X$, $y_1,y_2\in y_0+\delta_1 B_Y$, где $I(x,y)=\{i\in I : f(x,y)=f_i(x,y)\}$. Тогда f раздельно 2-липшицевая функция в окрестности (x_0,y_0).

Отметим, что если $I(x_0,y_0)$ состоит из одной точки, то существует $\delta_1>0$ такое, что $I(x_1,y_1)=I(x_2,y_2)$ и состоит из одной точки при $x_1,x_2\in x_0+\delta_1 B_X$, $y_1,y_2\in y_0+\delta_1 B_Y$.

Положим

$$f^+((x_0,y_0);(x,y))=\overline{\lim_{t\downarrow 0}}\frac{1}{t}(f(x_0+tx,y_0+ty)-f(x_0,y_0)),$$

$$f^-((x_0,y_0);(x,y))=\underline{\lim_{t\downarrow 0}}\frac{1}{t}(f(x_0+tx,y_0+ty)-f(x_0,y_0)),$$

$$f'((x_0,y_0);(x,y))=\lim_{t\downarrow 0}\frac{1}{t}(f(x_0+tx,y_0+ty)-f(x_0,y_0)).$$

Лемма 8. Если $f: X\times Y\to R$ бивыпуклая раздельно 2-липшицевая в точке (x_0,y_0) функция, то $f'((x_0,y_0);(x,y))=f'((x_0,y_0);(x,0))+f'((x_0,y_0);(0,y))$ при $(x,y)\in X\times Y$.

Доказательство. Ясно, что

$$f^+((x_0,y_0);(x,y)) = \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}(f((x_0,y_0)+\lambda(x,y)) - f(x_0,y_0)) =$$

$$= \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}\big[(f(x_0+\lambda x,y_0) - f(x_0,y_0)) + (f(x_0,y_0+\lambda y) - f(x_0,y_0)) +$$

$$+ (f(x_0+\lambda x,y_0+\lambda y) - f(x_0+\lambda x,y_0) - f(x_0,y_0+\lambda y) + f(x_0,y_0))\big] \le$$

$$\le \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}\Bigg[(f(x_0+\lambda x,y_0) - f(x_0,y_0)) + \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}(f(x_0,y_0+\lambda y) - f(x_0,y_0)) +$$

$$+ \overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}(f(x_0+\lambda x,y_0+\lambda y) - f(x_0+\lambda x,y_0) - f(x_0,y_0+\lambda y) + f(x_0,y_0)).$$

Так как f раздельно липшицевая в точке (x_0,y_0) функция, то

$$\overline{\lim_{\lambda\downarrow 0}}\frac{1}{\lambda}(f(x_0+\lambda x,y_0+\lambda y) - f(x_0+\lambda x,y_0) - f(x_0,y_0+\lambda y) - f(x_0,y_0)) \le \overline{\lim_{\lambda\downarrow 0}}\ \frac{L\|\lambda x\|\cdot\|\lambda y\|}{\lambda} = 0.$$

Поэтому $f^+((x_0,y_0);(x,y)) \le f'((x_0,y_0);(x,0)) + f'((x_0,y_0);(0,y))$ при $(x,y)\in X\times Y$.

Аналогично проверяется, что

$$f^-((x_0,y_0);(x,y)) \ge f'((x_0,y_0);(x,0)) + f'((x_0,y_0);(0,y))$$

при $(x,y)\in X\times Y$. Тогда получим, что $f'((x_0,y_0);(x,y))$ существует и

$$f'((x_0,y_0);(x,y)) = f'((x_0,y_0);(x,0)) + f'((x_0,y_0);(0,y))$$

при $(x,y)\in X\times Y$. Лемма доказана.

Лемма 9. Если бивыпуклая функция $f: X\times Y\to R$ непрерывна в точке (x_0,y_0), то f удовлетворяет условию Липшица в некоторой окрестности точки (x_0,y_0).

Доказательство. По условию f непрерывна в точке (x_0,y_0). Поэтому существует $\delta>0$ такое, что $|f(x,y)-f(x_0,y_0)|<1$ при $\|x-x_0\|\le\delta,\ \|y-y_0\|\le\delta$. Тогда $f(x,y)\le f(x_0,y_0)+1$ при $\|x-x_0\|\le\delta,\ \|y-y_0\|\le\delta$. Ясно, что

$$|f(x_2,y_2)-f(x_1,y_1)| = |f(x_2,y_2)-f(x_2,y_1)+f(x_2,y_1)-f(x_1,y_1)| \le$$

$$\le |f(x_2,y_2)-f(x_2,y_1)| + |f(x_2,y_1)-f(x_1,y_1)|.$$

Так как функция $x\to f(x,\bar y)$ выпукла и $f(x,\bar y)\le f(x_0,y_0)+1$ при $\|x-x_0\|\le\delta,\ \|\bar y-y_0\|\le\delta$, то из доказательства теоремы 2.1 [14] вытекает, что

$$|f(x_2,\bar y)-f(x_1,\bar y)| \le \frac{4(f(x_0,y_0)+1-f(x_0,\bar y))}{\delta}\|x_2-x_1\| \le \frac{8}{\delta}\|x_2-x_1\|$$

при $\|x_2-x_1\|\le\frac{\delta}{2},\ \|x_1-x_0\|\le\frac{\delta}{2}$ и $\|\bar y-y_0\|\le\delta$. Аналогично получим, что

$|f(\bar x,y_2)-f(\bar x,y_1)| \le \frac{8}{\delta}\|y_2-y_1\|$ при $\|y_2-y_0\|\le\frac{\delta}{2},\ \|y_1-y_0\|\le\frac{\delta}{2}$ и $\|\bar x-x_0\|\le\delta$. Поэтому

$$|f(x_2,y_2)-f(x_1,y_1)| \le \frac{8}{\delta}(\|x_2-x_1\|+\|y_2-y_1\|)$$

при $\|x_2-x_0\|\le\frac{\delta}{2},\ \|x_1-x_0\|\le\frac{\delta}{2},\ \|y_2-y_0\|\le\frac{\delta}{2},\|y_1-y_0\|\le\frac{\delta}{2}$. Лемма доказана.

Если $f: R^n\times R^m\to R$ бивыпуклая функция, то аналогично теореме 35.1[15] получим, что f удовлетворяет условию Липшица на каждом компактном подмножестве в $R^n\times R^m$.

Из леммы 9 вытекает, что f субдифференцируема в смысле Кларка в точке (x_0,y_0) и субдифференциал в смысле Кларка $\partial_C f(x_0,y_0)$ непустое выпуклое слабо* компактное множество в $X^*\times Y^*$.

Пусть $f: X\times Y\to R$. Положим

$$f^0((x_0,y_0);(x,y)) = \overline{\lim_{\substack{z_1\to x_0,\\ z_2\to y_0,\lambda\downarrow 0}}}\ \frac{1}{\lambda}\big(f(z_1+\lambda x,z_2+\lambda y)-f(z_1,z_2)\big).$$

Лемма 10. Если бивыпуклая функция $f: X\times Y\to R$ непрерывна в точке (x_0,y_0) и удовлетворяет раздельно 2-липшицеву условию в окрестности (x_0,y_0), то

$$f^0((x_0,y_0);(x,y)) = f'((x_0,y_0);(x,y)) = f'((x_0,y_0);(x,0)) + f'((x_0,y_0);(0,y))$$

при $(x,y)\in X\times Y$.

Доказательство. Из леммы 8 и из определения $f^0((x_0,y_0);(x,y))$ вытекает, что $f^0((x_0,y_0);(x,y)) \ge f'((x_0,y_0);(x,y))$ при $(x,y) \in X \times Y$.

Докажем обратное неравенство. Ясно, что

$$f^0((x_0,y_0);(x,y)) = \overline{\lim_{\substack{z_1 \to x_0,\\ z_2 \to y_0\\ \lambda \downarrow 0}}} \frac{1}{\lambda}(f(z_1+\lambda x, z_2+\lambda y) - f(z_1,z_2)) \le$$

$$\le \overline{\lim_{\substack{z_1 \to x_0,\\ z_2 \to y_0\\ \lambda \downarrow 0}}} \frac{1}{\lambda}(f(z_1+\lambda x, z_2) - f(z_1,z_2)) + \overline{\lim_{\substack{z_1 \to x_0,\\ z_2 \to y_0\\ \lambda \downarrow 0}}} \frac{1}{\lambda}(f(z_1, z_2+\lambda y) - f(z_1,z_2)) +$$

$$+ \overline{\lim_{\substack{z_1 \to x_0,\\ z_2 \to y_0\\ \lambda \downarrow 0}}} \frac{1}{\lambda}(f(z_1+\lambda x, z_2+\lambda y) - f(z_1+\lambda x, z_2)) - f(z_1, z_2+\lambda y) + f(z_1,z_2)) \le$$

$$\le \overline{\lim_{\substack{z_1 \to x_0,\\ z_2 \to y_0\\ \lambda \downarrow 0}}} \frac{1}{\lambda}(f(z_1+\lambda x, z_2) - f(z_1,z_2)) + \overline{\lim_{\substack{z_1 \to x_0,\\ z_2 \to y_0\\ \lambda \downarrow 0}}} \frac{1}{\lambda}(f(z_1, z_2+\lambda y) - f(z_1,z_2)).$$

Пусть $M > f'((x_0,y_0);(x,0))$. Тогда существует $\lambda > 0$ такое, что $\frac{1}{\lambda}(f(x_0+\lambda x, y_0) - f(x_0,y_0)) < M$. По лемме 9 f непрерывная функция в окрестности точки (x_0,y_0). Поэтому не умаляя общности, можно считать, что $(z_1,z_2) \to \frac{1}{\lambda}(f(z_1+\lambda x, z_2) - f(z_1,z_2))$ непрерывная функция в (x_0,y_0) (выбирая λ достаточно малым, этого можно достичь). Пусть $\bar{\varepsilon} > 0$ такое, что $\frac{1}{\lambda}(f(x_0+\lambda x, y_0) - f(x_0,y_0)) < M - \bar{\varepsilon}$. Тогда для $\bar{\varepsilon}$ существует $\delta > 0$ такое, что

$$\frac{1}{\lambda}(f(z_1+\lambda x, z_2) - f(z_1,z_2) - f(x_0+\lambda x, y_0) + f(x_0,y_0)) \le \bar{\varepsilon}$$

при $\|z_1 - x_0\| \le \delta$, $\|z_2 - y_0\| \le \delta$. Отсюда вытекает, что $\frac{1}{\lambda}(f(z_1+\lambda x, z_2) - f(z_1,z_2)) < M$ при $\|z_1 - x_0\| \le \delta$, $\|z_2 - y_0\| \le \delta$. Так как функция $\frac{1}{h}(f(z_1+hx, z_2) - f(z_1,z_2))$ неубывающая по h, то получим, что $\frac{1}{h}(f(z_1+hx, z_2) - f(z_1,z_2)) < M$ при $\|z_1 - x_0\| \le \delta$, $\|z_2 - y_0\| \le \delta$ и $0 < h \le \lambda$. Поэтому

$$\sup\{\frac{1}{h}(f(z_1+hx, z_2) - f(z_1,z_2)) : \|z_1 - x_0\| \le \delta, \|z_2 - y_0\| \le \delta, 0 < h \le \lambda\} \le M.$$

Отсюда вытекает, что $\overline{\lim_{\substack{z_1 \to x_0\\ z_2 \to y_0\\ h \downarrow 0}}} \frac{1}{h}(f(z_1+hx, z_2) - f(z_1,z_2)) \le M$.

Так как последнее соотношение верно для всякого $M > f'((x_0,y_0);(x,0))$, то

$$\overline{\lim_{\substack{z_1 \to x_0\\ z_2 \to y_0\\ h \downarrow 0}}} \frac{1}{h}(f(z_1+hx, z_2) - f(z_1,z_2)) \le f'((x_0,y_0);(x,0)).$$

Аналогично получим

$$\overline{\lim_{\substack{z_1 \to x_0\\ z_2 \to y_0\\ h \downarrow 0}}} \frac{1}{h}(f(z_1, z_2+hy) - f(z_1,z_2)) \le f'((x_0,y_0);(0,y)).$$

Тогда по лемме 8 имеем

$$f^0((x_0,y_0);(x,y)) \le f'((x_0,y_0);(x,0)) + f'((x_0,y_0);(0,y)) = f'((x_0,y_0);(x,y)).$$

Отсюда вытекает справедливость леммы. Лемма доказана.

Пусть $f_i \in A(X \times Y)$ при $i = 0,1,\dots,m$. Рассмотрим задачу

$$f_0(x,y) \to \min, \quad (x,y) \in \{(x,y) \in X \times Y : f_i(x,y) \le 0, \quad i = 1,\dots,m,$$

$$x_i^*(x,y) + v_i^*(x) + y_i^*(y) + c_i = 0 \text{ при } i = m+1,\dots,k, (x,y) \in C\}. \qquad (18)$$

Так как $f_i \in A(X \times Y)$ при $i = 0,1,\dots,m$, то

$$f_i(\bar{x}+x,\bar{y}+y)-f_i(\bar{x},\bar{y})=\sup_{t\in T_i}(x_t^*(\bar{x}+x,\bar{y}+y)+v_t^*(\bar{x}+x)+y_t^*(\bar{y}+y)+c_t)-$$

$$-\sup_{t\in T_i}(x_t^*(\bar{x},\bar{y})+v_t^*(\bar{x})+y_t^*(\bar{y})+c_t)\le\sup_{t\in T_i}(x_t^*(x,y)+x_t^*(x,\bar{y})+x_t^*(\bar{x},y)+v_t^*(x)+y_t^*(y))\le$$

$$\le\sup_{t\in T_i}x_t^*(x,y)+\sup_{t\in T_i}(x_t^*(x,\bar{y})+x_t^*(\bar{x},y)+v_t^*(x)+y_t^*(y))$$

при $(x,y)\in X\times Y$. Если $\left|x_t^*(x,y)\right|\le L_i\|x\|\|y\|$ при $(x,y)\in X\times Y$, то имеем, что

$$\frac{\sup\limits_{t\in T_i}x_t^*(x,y)}{\|x\|+\|y\|}\le\frac{L_i\|x\|\|y\|}{\|x\|+\|y\|}\le\frac{L_i(\|x\|+\|y\|)^2}{2(\|x\|+\|y\|)}=\frac{L_i}{2}(\|x\|+\|y\|)$$

при $(x,y)\in X\times Y$. Поэтому $\sup\limits_{t\in T_i}\left|x_t^*(x,y)\right|\le\frac{L_i}{2}(\|x\|+\|y\|)^2=o(\|x\|+\|y\|)$ при $(x,y)\in X\times Y$.

Если существуют числа $L_i>0,\ K_i>0,\ M_i>0$ и C_i такие, что $\left|x_t^*(x,y)\right|\le L_i\|x\|\|y\|$, $\left|v_t^*(x)\right|\le K_i\|x\|$, $\left|y_t^*(y)\right|\le M_i\|y\|$, $|c_t|\le C_i$ при $t\in T_i$, то имеем, что

$$\sup_{t\in T_i}(x_t^*(x,\bar{y})+x_t^*(\bar{x},y)+v_t^*(x)+y_t^*(y))\le L_i\|x\|\|\bar{y}\|+L_i\|\bar{x}\|\|y\|+K_i\|x\|+M_i\|y\|$$

при $(x,y)\in X\times Y$. Тогда из теоремы 3.2.1[16] следует, что

$$\varphi_i(x,y)=\sup_{t\in T_i}(x_t^*(x,\bar{y})+x_t^*(\bar{x},y)+v_t^*(x)+y_t^*(y))$$

сублинейная непрерывная функция при $i=0,1,\dots,m$.

Если $i=m+1,\dots,k,$ то положив $f_i(x,y)=x_i^*(x,y)+v_i^*(x)+y_i^*(y)+c_i$ имеем, что

$$f_i(\bar{x}+x,\bar{y}+y)-f_i(\bar{x},\bar{y})=x_i^*(\bar{x}+x,\bar{y}+y)+v_i^*(\bar{x}+x)+y_i^*(\bar{y}+y)+c_i-$$

$$-(x_i^*(\bar{x},\bar{y})+v_i^*(\bar{x})+y_i^*(\bar{y})+c_i)=x_i^*(x,y)+x_i^*(x,\bar{y})+x_i^*(\bar{x},y)+v_i^*(x)+y_i^*(y)$$

при $(x,y)\in X\times Y$. Если $\|x\|+\|y\|\le\varepsilon$ и $\|u\|+\|v\|\le\varepsilon$, то имеем, что

$$f_i(\bar{x}+x,\bar{y}+y)-f_i(\bar{x}+u,\bar{y}+v)=x_i^*(\bar{x}+x,\bar{y}+y)+v_i^*(\bar{x}+x)+y_i^*(\bar{y}+y)+c_i-$$

$$-x_i^*(\bar{x}+u,\bar{y}+v)-v_i^*(\bar{x}+u)-y_i^*(\bar{y}+v)-c_i=x_i^*(x,\bar{y})+x_i^*(\bar{x},y)+x_i^*(x,y)-$$

$$-x_i^*(u,\bar{y})-x_i^*(\bar{x},v)-x_i^*(u,v)+v_i^*(x-u)+y_i^*(y-v).$$

Поэтому

$$\left|f_i(\bar{x}+x,\bar{y}+y)-f_i(\bar{x}+u,\bar{y}+v)-x_i^*(x-u,\bar{y})-x_i^*(\bar{x},y-v)-v_i^*(x-u)-y_i^*(y-v)\right|=$$

$$=\left|x_i^*(x,y)-x_i^*(x,v)+x_i^*(x,v)-x_i^*(u,v)\right|\le L_i\|x\|\|y-v\|+L_i\|v\|\|x-u\|\le L_i\varepsilon(\|y-v\|+\|x-u\|),$$

т.е. функция $f_i(x,y)=x_i^*(x,y)+v_i^*(x)+y_i^*(y)+c_i$ строго дифференцируема в точке $(\bar{x},\bar{y})$ при $i=m+1,\dots,k$.

Тогда из теоремы 3 следует следующее следствие.

Следствие 9. Если X и Y банаховы пространства, (x_0,y_0)-точка локального минимума в задаче (18), $f_i\in A(X\times Y)$, т.е. $f_i(x,y)=\sup\limits_{t\in T_i}(x_t^*(x,y)+v_t^*(x)+y_t^*(y)+c_t)$ собственные функции, $f_j(x_0,y_0)=0$ при $j=1,\dots,m$, существуют числа $L_i>0,\ K_i>0,\ M_i>0$ и C_i такие, что $\left|x_t^*(x,y)\right|\le L_i\|x\|\|y\|$, $\left|v_t^*(x)\right|\le K_i\|x\|$, $\left|y_t^*(y)\right|\le M_i\|y\|$, $|c_t|\le C_i$ при $t\in T_i$, $i=0,1,\dots,m$, $\varphi_i(x,y)=\sup\limits_{t\in T_i}(x_t^*(x,y_0)+x_t^*(x_0,y)+v_t^*(x)+y_t^*(y))$ при $i=0,1,\dots,m$ и функции $\varphi_i(x,y)=x_i^*(x,y_0)+x_i^*(x_0,y)+v_i^*(x)+y_i^*(y)$ линейны независимы при $i=m+1,\dots,k$, $C\subset X\times Y$, $I_C(x_0,y_0)\ne\varnothing$, то существуют одновременно не равные нулю $\alpha_0\ge0,\ \alpha_1\ge0,\dots,\alpha_m\ge0$, $\alpha_{m+1},\dots,\alpha_k$ такие, что $\sum\limits_{i=0}^{m}\alpha_i\varphi_i(x,y)+\sum\limits_{i=m+1}^{k}\alpha_i\varphi_i(x,y)\ge0$ при $(x,y)\in T_C(x_0,y_0)$.

2. О небходимых условиях второго порядка

Пусть $e(x,a)=\max\limits_{0\le i\le m}(\varphi_i(x)+a_i)$, где $\varphi_i: X\to R$ сублинейные непрерывные функции при $i\in\{0,1,\dots,m\}$, $\Lambda: X\to Y$ линейный непрерывный сюръективный оператор, T выпуклый замкнутый конус, $\operatorname{int} T\bigcap \operatorname{Ker}\Lambda\neq\varnothing$ и $\max\limits_{0\le i\le m}\varphi_i(x)\ge 0$ при $x\in \operatorname{int} T\bigcap \operatorname{Ker}\Lambda$. Положим

$$V(x,y,a)=e(x,a)+\delta_T(x)+\delta_{\operatorname{graph}\Lambda}(x,-y)=e(x,a)+\delta_{T\cap\Lambda^{-1}(y)}(x).$$

Легко проверяется, что $V(x,y,a)$ сублинейная пн.сн. функция и $g(y,a)=\inf\limits_{x\in X}V(x,y,a)$ сублинейная функция.

Пусть X отделимое локально выпуклое пространство, $T\subset X$ выпуклый конус. Положим $N=T^-=\{p\in X^*:\langle p,x\rangle\le 0 \text{ при } x\in T\}$, где T^- отрицательный полярный конус к конусу T.

Пусть $e(x,a)=\max\limits_{0\le i\le m}(\varphi_i^1(x)+a_i))$, где $\varphi_i: X\to R$ сублинейные непрерывные функции при $i\in\{0,1,\dots,m\}$, $\Lambda: X\to Y$ линейный непрерывный сюръективный оператор, T выпуклый замкнутый конус, $\max\limits_{0\le i\le m}\varphi_i(x)\ge 0$ при $x\in\{z\in T:\Lambda z=0\}$, $\operatorname{int} T\bigcap \operatorname{Ker}\Lambda\neq\varnothing$. Обозначим $N=T^-$, где T^- отрицательный полярный конус. Положим

$$V(x,y,a)=e(x,a)+\delta_T(x)+\delta_{\operatorname{graph}(\Lambda^{-1})}(y,x)=e(x,a)+\delta_{T\cap\Lambda^{-1}(y)}(x).$$

Так как сумма сублинейных пн.сн. функций сублинейная, то $V(x,y,a)$ сублинейная пн.сн. функция. Из предложения 2.5[17] следует, что $g(y,a)=\inf\limits_{x\in X}V(x,y,a)$ выпуклая функция. Ясно, что $g(\lambda(y,a))=\inf\limits_{x\in X}V(x,\lambda y,\lambda a)=\lambda\inf\limits_{x\in X}V(\frac{1}{\lambda}x,y,a)=\lambda\inf\limits_{x\in X}V(x,y,a)$. Поэтому $g(y,a)=\inf\limits_{x\in X}V(x,y,a)$ сублинейная функция. Отметим, что при данных условиях можно проверить, что $g(y,a)=\inf\limits_{x\in X}V(x,y,a)$ является непрерывной функцией.

Лемма 11. Пусть X отделимое локально выпуклое пространство, $e(x,a)=\max\limits_{0\le i\le m}(\varphi_i^1(x)+a_i))$, где $\varphi_i: X\to R$ сублинейные непрерывные функции при $i\in\{0,1,\dots,m\}$, $\Lambda: X\to Y$ линейный непрерывный сюръективный оператор, T выпуклый замкнутый конус, $\max\limits_{0\le i\le m}\varphi_i(x)\ge 0$ при $x\in\{z\in T:\Lambda z=0\}$, $\operatorname{int} T\bigcap \operatorname{Ker}\Lambda\neq\varnothing$. Тогда $(y^*,b)\in\partial g(0,0)$ в том и только в том случае, когда существует $\alpha_i\ge 0$, $\sum\limits_{i=0}^m\alpha_i=1$ такое, что $-\Lambda^*y^*\in\sum\limits_{i=0}^m\alpha_i\partial\varphi_i(0)+N$ и $b=\alpha=(\alpha_0,\alpha_1,\dots,\alpha_m)$.

Доказательство. Обозначим $a=(a_0,a_1,\dots,a_m)$. По условию имеем, что

$$g(0,0)=\inf_{x\in X}(\,e(x,0)+\delta_T(x)+\delta_{\operatorname{graph}\Lambda}(x,0))=e(0,0)+\delta_T(0)+\delta_{\operatorname{graph}\Lambda}(0,0)=V(0,0,0)=0.$$

Тогда аналогично предложению 4.3 [17] имеем, что $(y^*,b)\in\partial g(0,0)$ в том и только в том случае, когда $(0,y^*,b)\in\partial V(0,0,0)$. Обозначим

$$f_1(x,y,a)=e(x,a),\ f_2(x,y,a)=\delta_T(x),\ f_3(x,y,a)=\delta_{\operatorname{graph}(\Lambda^{-1})}(y,x).$$

Из условия и следствия 6.6.8[18] следует, что

$$\partial V(0,0,0)=\partial f_1(0,0,0)+\partial f_2(0,0,0)+\partial f_3(0,0,0),$$

$$(0,y^*,b)\in\partial f_1(0,0,0)+\partial f_2(0,0,0)+\partial f_3(0,0,0),$$

где $\partial f_2(0,0,0)=(\partial\delta_T(0),0,0)$, $\partial f_2(0,0,0)=(\partial\delta_{\operatorname{graph}\Lambda}(0,0),0)$. Обозначив

$$e(x,a)=\max_{0\le i\le m}(\varphi_i^1(x)+a_i)=\max_{0\le i\le m}(\varphi_i^1(x)+\langle(0,\dots0,1,0\dots,0),(0,\dots0,a_i,0\dots,0)\rangle),$$

по теореме Дубовицкого-Милютина ([19], с.234) имеем, что

$$\partial e(0,0)=\operatorname{co}\{(p_0,1,0,\dots0),(p_1,0,1,0,\dots0),\dots,(p_m,0,\dots0,1):p_i\in\partial\varphi_i^1(0)\}=$$

$$=\{(\sum_{i=0}^m\lambda_ip_i,\lambda_0,\lambda_1,\dots,\lambda_m):\ \lambda_i\ge 0,\ \sum_{i=0}^m\lambda_i=1,\ p_i\in\partial\varphi_i^1(0)\}.$$

Поэтому

$$(0,y^*,b)\in\{(\sum_{i=0}^m\lambda_i\partial\varphi_i^1(0),0,\lambda_0,\lambda_1,\dots,\lambda_m):\ \lambda_i\ge 0,\ \sum_{i=0}^m\lambda_i=1\}+(N,0,0)+\partial f_3(0,0,0).$$

Если $(x^*,y^*)\in\partial\delta_{\operatorname{graph}\Lambda}(0,0)$, то по определению субдифференциала имеем

$$\delta_{\text{graph}\,\Lambda}(x,-y) \ge \langle x^*,x\rangle + \langle y^*,-y\rangle$$

при $(x,y) \in X \times Y$. Поэтому $\langle x^*,x\rangle + \langle y^*,-\Lambda x\rangle \le 0$ при $x \in X$. Тогда $\langle x^*,-x\rangle + \langle y^*,\Lambda x\rangle \le 0$ или $\langle x^*,x\rangle + \langle y^*,-\Lambda x\rangle \ge 0$ при $x \in X$. Отсюда следует, что $\langle x^*,x\rangle + \langle y^*,-\Lambda x\rangle = 0$ при $x \in X$. Тогда имеем, что $\langle x^*,x\rangle - \langle \Lambda^* y^*,x\rangle = 0$ при $x \in X$, т.е. $x^* = \Lambda^* y^*$. Поэтому $(y^*,\Lambda^* y^*) \in \partial\delta_{\text{graph}\,\Lambda}(0,0)$. Имеем, что если $(0,y^*,b) \in \partial V(0,0,0)$, то существуют $\alpha_i \ge 0$, $\sum_{i=0}^{m}\alpha_i = 1$ и $(\bar{y}^*,\Lambda^*\bar{y}^*) \in \partial\delta_{\text{graph}\,\Lambda}(0,0)$ такие, что

$$(0,y^*,b) \in (\sum_{i=0}^{m}\alpha_i\partial\varphi_i^1(0),0,(\alpha_0,\alpha_1,\ldots,\alpha_m)) + (N,0,0) + (\Lambda^*\bar{y}^*,\bar{y}^*,0).$$

Отсюда следует, что $-\Lambda^* y^* \in \sum_{i=0}^{m}\alpha_i\partial\varphi_i(0) + N$ и $b = \alpha = (\alpha_0,\alpha_1,\ldots,\alpha_m)$. Лемма доказана.

Из доказательства леммы 11 следует, что

$$\partial g(0,0) = \{(y^*,\lambda_0,\lambda_1,\ldots,\lambda_m):\ \lambda_i \ge 0,\ \sum_{i=0}^{m}\lambda_i = 1,\ p_i \in \partial\varphi_i^1(0),\ x^* \in N,$$

$$y^* \in Y^*,\ \sum_{i=0}^{m}\lambda_i p_i + x^* + \Lambda^* y^* = 0\}.$$

Рассмотрим задачу

$$f_0(x) \to \min,\ \ f_j(x) \le 0,\ j = 1,2,\ldots,m,\ \ F(x) = 0,\ x \in C \quad (19)$$

где $f_j : B(x_0,2\delta) \to R$, $j \in I = \{0,1,\ldots,m\}$, $F : B(x_0,2\delta) \to Y$ оператор, $C \subset B(x_0,2\delta)$.

Положим $\Lambda x = F'(x_0)x$, $H = \{x \in X : \varphi_i^1(x) \le 0,\ i = 0,1,\ldots m,\ \Lambda x = 0,\ x \in I_C(x_0)\}$,

$g_{(a,y)}(x) = \max\limits_{0\le i\le m}(\varphi_i^1(x) + a_i) + \delta_{T_C(x_0)\cap\Lambda^{-1}(-y)}(x)$, где $(a,y) \in R^{m+1} \times Y$, $a = (a_0,a_1,\ldots,a_m)$.

Теорема 8. Если X и Y банаховы пространства, x_0 - точка локального минимума в задаче (19), $f_i(x_0) = 0$ при $i \in I$, функции f_i, $i \in I$, удовлетворяют $\varphi_i^1 + \varphi_i^2 - (o(2),\delta)$ локально верхнему полулипшицеву условию в точке x_0, $\varphi_i^1 : X \to R$ сублинейные непрерывные функции при $i \in I$, $\varphi_i^2 : X \to R$ положительные однородные степени 2 функции и удовлетворяют $(1,\mu,1,\delta)$, где $\mu > 1$, (или $(1,2,1,\delta,o(2))$) локально липшицеву условию с постоянной K в точке нуль при $i \in I$, отображение $F : X \to Y$ строго дифференцируемо в точке x_0, $F'(x_0)(X) = Y$ и F удовлетворяет $F'(x_0)x + S(x) - (o(2),\delta)$ локально липшицеву условию в точке x_0, $S : X \to Y$ положительный однородный степени 2 оператор и удовлетворяет $(1,\mu,1,\delta)$ (или $(1,2,1,\delta,\tilde{o}(2))$) локально липшицеву условию с постоянной K в точке нуль,

$\partial g^*_{(a,y)}(0) \ne \varnothing$ при $(a,y) \in R^{m+1} \times Y$, $C \subset X$ и $I_C(x_0) \cap \operatorname{Ker}\Lambda \ne \varnothing$, где $\Lambda x = F'(x_0)x$, то

$$E(h) = \sup\{\sum_{i=0}^{m}\lambda_i\varphi_i^2(h) + \langle y^*,S(h)\rangle : \lambda_i \ge 0,\ \sum_{i=0}^{m}\lambda_i = 1,\ p_i \in \partial\varphi_i^1(0),$$

$$x^* \in N_C(x_0),\ y^* \in Y^*,\ \sum_{i=0}^{m}\lambda_i p_i + \Lambda^* y^* + x^* = 0\} \ge 0$$

при $h \in H \cup \{0\}$.

Доказательство. Пусть $t \ge 0$, $t_1 \ge 0$, $t_2 \ge 0$. Так как $\varphi_i^2 : X \to R$ удовлетворяет $(1,\mu,1,\delta)$ локально липшицеву условию с постоянной K в точке нуль, то

$$\left|\varphi_i^2(t_1x_1 + t_2x_2) - \varphi_i^2(x_1)\right| \le Kt_2\|x_2\|(t_2^{\mu-1}\|x_2\|^{\mu-1} + \|t_1x_1\|^{\mu-1})$$

при $x_1,x_2 \in X$, $t_1\|x_1\| \le \delta$, $t_2\|x_2\| \le \delta$. Поэтому $\left|\varphi_i^2(tx)\right| \le Kt^{\mu}\|x\|^{\mu}$ при $t\|x\| \le \delta$, $i \in I$, где $\mu > 1$. По условию функции f_i, $i \in I$, удовлетворяют $\varphi_i^1 + \varphi_i^2 - (o(2),\delta)$ локально полулипшицеву условию в точке x_0. Поэтому

$$f_i(x_0 + tx) \le \varphi_i^1(tx) + \varphi_i^2(tx) + o(t^2\|x\|^2 \le \varphi_i^1(tx) + Kt^{\mu}\|x\|^{\mu} + o(t^2\|x\|^2)$$

при $x \in X$, $t\|x\| \le \delta$ и $i \in I$. Так как $S : X \to Y$ удовлетворяет $(1,\mu,1,\delta)$ локально липшицеву условию с постоянной K в точке нуль, где $\mu > 1$, то

$$\|S(t_1x_1+t_2x_2)-S(t_1x_1)\| \le Kt_2\|x_2\|(t_2^{\mu-1}\|x_2\|^{\mu-1}+\|t_1x_1\|^{\mu-1})$$

при $x_1, x_2 \in X$, $t_1\|x_1\| \le \delta$, $t_2\|x_2\| \le \delta$. Поэтому $\|S(tx)\| \le Kt^{\mu}\|x\|^{\mu}$ при $x \in X$, $t\|x\| \le \delta$.

Из неравенства $\|F(x_0+tx)-F(x_0)-F'(x_0)tx-S(tx)\| \le o(t^2\|x\|^2)$ при $x \in X$, $t\|x\| \le \delta$ имеем, что $\|F(x_0+tx)-F'(x_0)tx-F(x_0)\| \le Kt^{\mu}\|x\|^{\mu}+o(t^2\|x\|^2)$ при $x \in X$, $t\|x\| \le \delta$. Тогда из доказательства теоремы 3 следует, что $\max\limits_{0\le i\le m}\varphi_i(x) \ge 0$ при $x \in T_C(x_0) \cap \operatorname{Ker}\Lambda$.

Пусть $h \in H$. Рассмотрим задачу

$$\max_{0\le i\le m}(\varphi_i^1(x)+\varphi_i^2(h)) \to \inf \ , \ x \in T_C(x_0), \quad \Lambda x + S(h) = 0 .$$

Положим $a_i = \varphi_i^2(h)$, $y = S(h)$ и $g(y,a) = \inf\limits_{x\in T_C(x_0),\ \Lambda x+y=0} \max\limits_{0\le i\le m}(\varphi_i^1(x)+a_i)$. Из леммы 11 следует, что $(y^*,b) \in \partial g(0,0)$ в том и только в том случае, когда существуют $\alpha_i \ge 0$, $\sum\limits_{i=0}^{m}\alpha_i = 1$ такие, что $-\Lambda^* y^* \in \sum\limits_{i=0}^{m}\alpha_i\partial\varphi_i^1(0) + N_C(x_0)$ и $b = (\alpha_0,\alpha_1,\dots,\alpha_m)$. Поэтому

$$\partial g(0,0) = \{(y^*,\lambda_0,\lambda_1,\dots,\lambda_m) : \lambda_i \ge 0, \sum_{i=0}^{m}\lambda_i = 1, p_i \in \partial\varphi_i^1(0), x^* \in N_C(x_0),$$

$$y^* \in Y^*, \ \sum_{i=0}^{m}\lambda_i p_i + x^* + \Lambda^* y^* = 0\}.$$

По теореме Хермандера (см.[16, с.203]) имеем, что $g(y,a) = \sup\limits_{(y^*,\lambda)\in\partial g(0,0)}(\langle y^*,y\rangle + \sum\limits_{i=0}^{m}\lambda_i a_i)$. Так как $\partial g^*_{(a,y)}(0) \ne \varnothing$ при $(a,y) \in R^{m+1}\times Y$, то существует точка $x = \xi(h)$, где $x \in T_C(x_0)$, $\Lambda x + S(h) = 0$ такая, что

$$g(y,a) = \inf_{x\in T_C(x_0),\ \Lambda x+y=0} \max_{0\le i\le m}(\varphi_i^1(x)+a_i) = \max_{0\le i\le m}(\varphi_i^1(\xi(h))+\varphi_i^2(h)) =$$

$$= \sup_{(y^*,\lambda)\in\partial g(0,0)}(\langle y^*,y\rangle + \sum_{i=0}^{m}\lambda_i a_i) = \sup\{\langle y^*,y\rangle + \sum_{i=0}^{m}\lambda_i a_i : \lambda_i \ge 0, \sum_{i=0}^{m}\lambda_i = 1,$$

$$p_i \in \partial\varphi_i^1(0), x^* \in N_C(x_0), y^* \in Y^*, \sum_{i=0}^{m}\lambda_i p_i + x^* + \Lambda^* y^* = 0\}.$$

Поэтому

$$E(h) = g(S(h),\varphi^2(h)) = \max_{0\le i\le m}(\varphi_i^1(\xi(h))+\varphi_i^2(h)) = \sup\{\langle y^*,S(h)\rangle + \sum_{i=0}^{m}\lambda_i\varphi_i^2(h) : \lambda_i \ge 0,$$

$$\sum_{i=0}^{m}\lambda_i = 1, \sum_{i=0}^{m}\lambda_i p_i + x^* + \Lambda^* y^* = 0, \ p_i \in \partial\varphi_i^1(0), x^* \in N_C(x_0), y^* \in Y^*\},$$

где $\varphi^2(h) = (\varphi_0^2(h),\varphi_1^2(h),\dots,\varphi_m^2(h))$, $\Lambda\xi(h) + S(h) = 0$.

Так как F удовлетворяет $F'(x_0)x + S(x) - (o(2),\delta)$ локально липшицеву условию с постоянной K в точке x_0, то

$$\|F(x_0+th+t^2\xi)-F(x_0)-\Lambda(th+t^2\xi)-S(th+t^2\xi)\| \le o(\|th+t^2\xi\|^2)$$

при $t \in [0,t_0]$, где $t_0 = \min\{1, \frac{\delta}{\|h\|+\|\xi\|+1}\}$. Поэтому из соотношения $\Lambda h = 0$ и $\Lambda\xi + S(h) = 0$ вытекает, что

$$\|F(x_0+th+t^2\xi)-F(x_0)+S(th)-S(th+t^2\xi)\| \le o(\|th+t^2\xi\|^2)$$

при $t \in [0,t_0]$. Отсюда имеем, что $\|F(x_0+th+t^2\xi)\| \le \|S(th+t^2\xi)-S(th)\| + o(\|th+t^2\xi\|^2) \le$

$$\le Kt^2\|\xi\|(\|th\|^{\mu-1}+\|t^2\xi\|^{\mu-1}) + o(\|th+t^2\xi\|^2) = o_1(t^2)$$

при $t \in [0,t_0]$, где $\frac{o_1(t)}{t} \to 0$ при $t \downarrow 0$. По теореме Люстерника[12, с.41] существуют $r : R_+ \to X$ и число $m > 0$ такие, что $F(x_0+th+t^2\xi+r(t)) = 0$, $\|r(t)\|_k \le m\|F(x_0+th+t^2\xi\| = o_2(t^2)$ при $t \in [0,t_0]$, где $r(t) = x(x_0+th+t^2\xi)$, $o_2(t) = m\,o_1(t)$, $\frac{o_2(t)}{t} \to 0$ при $t \downarrow 0$.

Кроме того имеем, что существует число $t_1 > 0$, где $t_1 \le t_0$, такое, что

$$f_i(x_0 + th + t^2\xi + r(t)) - f_i(x_0) - \varphi_i^1(th + t^2\xi + r(t)) - \varphi_i^2(th + t^2\xi + r(t)) \le o(\|th + t^2\xi + r(t)\|^2)$$

при $t \in [0, t_1]$. По условию $\varphi_i^1(x)$ сублинейная непрерывная функция в X. Тогда существует число $c > 0$ такое, что $|\varphi_i^1(x)| \le c\|x\|$ при $x \in X$ и $i \in I$. Поэтому $\lim\limits_{t\downarrow 0} \frac{1}{t^2}\varphi_i^1(r(t)) = \lim\limits_{t\downarrow 0} \varphi_i^1(\frac{1}{t^2} r(t)) = 0$, т.е. $\varphi_i^1(r(t)) = o_3(t^2)$, где $\frac{o_3(t)}{t} \to 0$ при $t \downarrow 0$. Тогда отсюда следует, что

$$f_i(x_0 + th + t^2\xi + r(t)) - f_i(x_0) \le \varphi_i^1(th + t^2\xi + r(t)) + \varphi_i^2(th + t^2\xi + r(t)) - \varphi_i^2(th) +$$
$$+ \varphi_i^2(th) + o(\|th + t^2\xi + r(t)\|_k^2) \le \varphi_i^1(th) + \varphi_i^1(t^2\xi) + \varphi_i^1(r(t)) + o(\|th + t^2\xi + r(t)\|_k^2) +$$
$$+ K\|t^2\xi + r(t)\|(\|th\|^{\mu-1} + \|t^2\xi + r(t)\|^{\mu-1}) + \varphi_i^2(th) \le t^2\varphi_i^1(\xi) + t^2\varphi_i^2(h) + o_4(t^2)$$

при $t \in [0, t_1]$, где $\frac{o_4(t)}{t} \to 0$ при $t \downarrow 0$. Положив $f(x) = \max\limits_{0\le i\le m} f_i(x)$ имеем, что

$$f(x_0 + th + t^2\xi + r(t)) = \max_{0\le i\le m} f_i(x_0 + th + t^2\xi + r(t)) \le t^2 \max_{0\le i\le m}(\varphi_i^1(\xi) + \varphi_i^2(h)) + o_4(t^2) \text{ при } t \in [0, t_1].$$

Так как $h \in I_C(x_0)$, то по определению $I_C(x_0)$ существует $\alpha_0 > 0$ такое, что $x_0 + th + t^2\xi + r(t) \in C$ при $t \in [0, \alpha_0]$.

Если допустить, что $E(h) < 0$, то имеем $f(x_0 + th + t^2\xi + r(t)) < 0$ при малых $t > 0$. Так как x_0 - точка локального минимума в задаче (19), то получим противоречие. Теорема доказана.

Замыкание множества H в X обозначим через clH. Если $H \ne \varnothing$, то при условии теоремы 8 имеем, что

$$clH = \{x \in X : \varphi_i^1(x) \le 0,\ i = 0,1,\dots m,\ F'(x_0)x = 0,\ x \in T_C(x_0)\}.$$

Поэтому если $H \ne \varnothing$, $h \to E(h)$ непрерывная функция в clH и выполняются условия теоремы 8, то $E(h) \ge 0$ при $h \in clH$.

Отметим, что если C выпуклое множество и $\operatorname{int} C \ne \varnothing$, то из леммы (см.[2, с.95]) следует, что $I_C(x_0) \ne \varnothing$.

Рассмотрим задачу (18). Если $\bar f_i(x, y) = x_i^*(x, y)$ при $i = m+1, \dots, k$, то

$$|\bar f_i(x + u, y + v) - \bar f_i(x, y)| = |x_i^*(x + u, y + v) - x_i^*(x, y)| \le |x_i^*(u, y)| + |x_i^*(x, v)| +$$
$$+ |x_i^*(u, v)| \le L_i\|u\|\|y\| + L_i\|x\|\|v\| + L_i\|u\|\|v\| \le L_i(\|x\| + \|y\|)(\|u\| + \|v\|) +$$
$$+ \frac{L_i}{2}(\|u\| + \|v\|)^2 \le L_i(\|u\| + \|v\|)((\|u\| + \|v\|) + (\|x\| + \|y\|)),$$

т.е. функция $\bar f_i(x, y) = x_i^*(x, y)$ удовлетворяет $(1,2,1,\delta)$ локально липшицеву условию с постоянной L_i в точке нуль при $\delta > 0$.

Если $\bar f_i(x, y) = \sup\limits_{t\in T_i} x_t^*(x, y)$ при $i = 1, \dots, m$, то

$$\bar f_i(x + u, y + v) - \bar f_i(x, y) = \sup_{t\in T_i} x_t^*(x + u, y + v) - \sup_{t\in T_i} x_t^*(x, y) \le \sup_{t\in T_i}(x_t^*(x + u, y + v) - x_t^*(x, y)) =$$
$$= \sup_{t\in T_i}(x_t^*(u, v) + x_t^*(x, v) + x_t^*(u, y)) \le L_i\|u\|\|y\| + L_i\|x\|\|v\| + L_i\|u\|\|v\| \le L_i(\|x\| + \|y\|)(\|u\| + \|v\|) +$$
$$+ \frac{L_i}{2}(\|u\| + \|v\|)^2 \le L_i(\|u\| + \|v\|)((\|u\| + \|v\|) + (\|x\| + \|y\|)).$$

Аналогично имеем, что

$$\bar f_i(x + u, y + v) - \bar f_i(x, y) = \sup_{t\in T_i} x_t^*(x + u, y + v) - \sup_{t\in T_i} x_t^*(x, y) \ge \sup_{t\in T_i}(x_t^*(x + u, y + v) -$$
$$- x_t^*(x, y)) = \inf_{t\in T_i}(x_t^*(u, v) + x_t^*(x, v) + x_t^*(u, y)) \ge -L_i\|u\|\|y\| - L_i\|x\|\|v\| - L_i\|u\|\|v\| \ge$$
$$- L_i(\|x\| + \|y\|)(\|u\| + \|v\|) - \frac{L_i}{2}(\|u\| + \|v\|)^2 \ge -L_i(\|u\| + \|v\|)((\|u\| + \|v\|) + (\|x\| + \|y\|)).$$

Поэтому $\left|\bar{f}_i(x+u,y+v)-\bar{f}_i(x,y)\right| \le L_i(\|u\|+\|v\|)((\|u\|+\|v\|)+(\|x\|+\|y\|))$, т.е. функция $\bar{f}_i(x,y)=\sup\limits_{t\in T_i} x_t^*(x,y)$ удовлетворяет (1,2,1,δ) локально липшицеву условию с постоянной L_i в точке нуль при $\delta>0$, где $i=1,\dots,m$.

Пусть $g_{(a,r)}(x,y)=\max\limits_{0\le i\le m}(\varphi_i^1(x,y)+a_i)+\delta_{T_C(x_0,y_0)\cap S_r)}(x,y)$, где $(a,r)\in R^{m+1}\times R^{k-m}$,

$\varphi_i^1(x,y)=\sup\limits_{t\in T_i}(x_t^*(x,y_0)+x_t^*(x_0,y)+v_t^*(x)+y_t^*(y))$, $\varphi_i^2(h)=\sup\limits_{t\in T_i} x_t^*(h_1,h_2)$ при $i=0,1,\dots,m$,

$\varphi_i^1(x,y)=x_i^*(x,y_0)+x_i^*(x_0,y)+v_i^*(x)+y_i^*(y)$, $\varphi_i^2(h)=x_i^*(h_1,h_2)$ при $i=m+1,\dots,k$,

$S_r=\{(x,y)\in X\times Y:\varphi_i^1(x,y)+r_i=0 \text{ при } i=m+1,\dots,k\}$, $r=(r_{m+1},\dots,r_k)$, $a=(a_1,\dots,a_m)$.

Следствие 10. Если X и Y банаховы пространства, (x_0,y_0)-точка локального минимума в задаче (18), $f_i(x,y)=\sup\limits_{t\in T_i}(x_t^*(x,y)+v_t^*(x)+y_t^*(y)+c_t)$ бивыпуклые функции и $f_i(x_0,y_0)=0$ при $i=0,1,\dots,m$, существуют числа $L_i>0, K_i>0, M_i>0$ и C_i такие, что $\left|x_t^*(x,y)\right|\le L\|x\|\|y\|$, $\left|v_t^*(x)\right|\le K_i\|x\|$, $\left|y_t^*(y)\right|\le M_i\|y\|$, $|c_t|\le C_i$ при $t\in T_i$,

$f_i(x,y)=x_i^*(x,y)+v_i^*(x)+y_i^*(y)+c_i$ при $i=m+1,\dots,k$, функции $\varphi_i^1(x,y)=x_i^*(x,y_0)+x_i^*(x_0,y)+v_i^*(x)+y_i^*(y)$ линейно независимы при $i=m+1,\dots,k$, $C\subset X\times Y$, $I_C(x_0,y_0)\ne\varnothing$, $\partial g_{(a,r)}^*(0,0)\ne\varnothing$ при $(a,r)\in R^{m+1}\times R^{k-m}$ и $I_C(x_0,y_0)\bigcap S_0\ne\varnothing$, то

$$E(h)=\sup\{\sum_{i=0}^{m}\lambda_i\varphi_i^2(h)+\sum_{i=m+1}^{k}\lambda_i\varphi_i^2(h):\lambda_i\ge 0,\ \sum_{i=0}^{m}\lambda_i=1,\ (x^*,y^*)\in N_C(x_0,y_0),\ t\in T_i,$$

$$\sum_{i=0}^{m}\lambda_i(x_{ti}^*(\cdot,y_0)+v_{ti}^*,x_{ti}^*(x_0,\cdot)+y_{ti}^*)+\sum_{i=m+1}^{k}\lambda_i(x_i^*(\cdot,y_0)+v_i^*,x_i^*(x_0,\cdot)+y_i^*)+(x^*,y^*))=0\}\ge 0$$

при $h=(h_1,h_2)\in H\bigcup\{0\}$, где $H=\{(x,y)\in X\times Y:\varphi_i^1(x,y)\le 0,\ i=0,1,\dots m,\ (x,y)\in S_0,\ (x,y)\in I_C(x_0,y_0)\}$.

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MEDICAL SCIENCES

USE OF ANTIHYPERTENSIVE DRUGS AMONG MEDICAL UNIVERSITY STUDENTS: A CROSS-SECTIONAL STUDY

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Abstract

Objective. To assess the range of medications and analyze the real-world use of antihypertensive drugs among medical university students (Grodno, Belarus).

Methods. An anonymous survey of 162 students of Grodno State Medical University (years 1–5) was conducted using a Google Forms questionnaire. Data were collected on the presence of elevated blood pressure, non-pharmacological methods of its correction, antihypertensive drug therapy, and students' lifestyle characteristics, including physical activity, smoking, alcohol consumption, intake of table salt, coffee, and caffeine-containing beverages.

Results. Elevated blood pressure was identified in 21.6% of respondents. Antihypertensive drugs are currently used or have been used by 17.3% of students. The most commonly used medications were angiotensin-converting enzyme (ACE) inhibitors (enalapril 39.3%, lisinopril 25.0%) and modern β-blockers (bisoprolol 21.4%, nebivolol 14.3%). Economic factors significantly influence drug choice, with low-cost generics predominating. Treatment adherence was low, with 32% of students reporting forgetting to take medications on time. Non-pharmacological methods were used by 25% of students with arterial hypertension.

Conclusion. The findings highlight the need to strengthen educational efforts aimed at early detection of arterial hypertension, its prevention, and improving adherence to antihypertensive therapy among medical students.

Keywords: arterial hypertension; medical students; antihypertensive drugs; adherence

Introduction

According to WHO data, cardiovascular diseases (CVDs), primarily arterial hypertension (AH), remain one of the leading causes of mortality and disability worldwide, including in the Republic of Belarus [1]. Despite significant advances in prevention and treatment, hypertension continues to have a substantial impact on morbidity patterns and demographic trends. Epidemiological data indicate that nearly one in five Belarusian residents over the age of 18 has elevated blood pressure [2].

These findings are fully consistent with large-scale pharmacoepidemiological studies previously conducted in Belarus among adults aged 25–64 years, which showed that every second rural resident had elevated blood pressure (50.2%), while in urban populations the figure was slightly lower (39.2%). In addition, high dietary salt intake and a high prevalence of disturbances in glucose and lipid metabolism have been identified, highlighting the need to strengthen both primary and secondary prevention of hypertension [3].

In the overall mortality structure of the Belarusian population, diseases of the circulatory system consistently account for more than half of all deaths, and in certain periods up to 60%, making them the leading cause of premature mortality [4].

Arterial hypertension is a major risk factor for myocardial infarction and stroke. According to the Ministry of Health and the Republican Scientific and Practical Center "Cardiology," in recent years (2025–2026), more than 2.2 million residents of Belarus have been diagnosed with arterial hypertension [5]. The situation is particularly unfavorable regarding hypertension-related complications among individuals who abuse alcohol [6].

One of the most relevant challenges in modern healthcare is the rational use of medicines in the treatment of arterial hypertension [7]. In-depth knowledge of pharmacoepidemiology and pharmacoeconomics allows for the identification of key clinical principles for the appropriate selection and evaluation of antihypertensive therapy. This contributes to the optimization and individualization of pharmacotherapy, improves patient adherence, enhances rational drug use, reduces treatment costs, and increases safety [8].

Considerable experience in pharmacoepidemiology and pharmacoeconomics of hypertension has been accumulated in CIS countries and is actively used to improve the rational pharmacotherapy of this disease [9–13].

In recent years, antihypertensive therapy has undergone significant changes in accordance with international ESC/ESH guidelines for 2018–2023 [14,15]. In young patients, including students, preference is

given to ACE inhibitors/angiotensin receptor blockers (ARBs), calcium channel blockers, and modern selective β-blockers due to their favorable safety profile, minimal impact on quality of life, and proven organ-protective effects [16–18].

Medical university students represent a specific population group. On the one hand, they possess a high level of medical knowledge, which theoretically should promote informed therapeutic decisions and high treatment adherence. On the other hand, they are exposed to chronic stress, sleep deprivation (often 5–6 hours per day), increased caffeine and salt consumption, smoking, and irregular physical activity. These risk factors, as demonstrated in numerous recent studies, contribute to the early development of arterial hypertension already at the age of 16–24 years [19,20].

Pharmacoepidemiological studies of hypertension among young populations conducted in different regions show that the prevalence of elevated blood pressure among medical students ranges from 15% to 25%. This is comparable to the general young population; however, it is characterized by lower-than-expected adherence for individuals with medical education. Economic factors play a key role in drug selection, especially under conditions of limited student budgets [21,22].

Materials and Methods

An anonymous survey was conducted among 162 students of Grodno State Medical University (years 1–5) using a Google Forms questionnaire.

Data were collected and analyzed regarding demographics and lifestyle factors (smoking, alcohol consumption, energy drinks, coffee intake, physical activity, stress level, sleep duration, and salt consumption), the presence of elevated blood pressure, frequency of blood pressure measurement, use of antihypertensive medications (drug names, source of prescription, adherence, and adverse effects), non-pharmacological correction methods, knowledge of target blood pressure values, and frequency of medical consultations.

Statistical analysis was descriptive and included absolute and relative values.

For pharmacoeconomic analysis, current data from pharmacies in the Republic of Belarus (103.by, apte4ka.by, 2026) were used. All prices were converted to US dollars using the exchange rate of the National Bank of the Republic of Belarus as of April 11, 2026 (2.8894 BYN per 1 USD).

Results and Discussion

The age distribution of respondents was as follows: 16–17 years — 18%, 18–19 years — 62%, 20–21 years — 15%, and over 21 years — 5%. Females accounted for 68% of participants, while males represented 32%.

Stress levels were assessed using a 10-point scale [23]. A significant proportion (43.2%) of respondents rated their stress as high (8–10 points). Insufficient sleep duration (up to 5 hours) was reported by two-thirds of students (67.9%), daily consumption of coffee and/or caffeine-containing energy drinks by 71.4%, smoking by 62.5%, and increased salt intake (self-reported preference for salty foods) by 42%. These risk factors correlate with increased student attention to blood pressure monitoring and awareness of the role of lifestyle factors in the development of hypertension in young individuals.

Elevated blood pressure was diagnosed by a physician in 21.6% of respondents. In other cases, students suspected elevated blood pressure themselves prior to measurement. Antihypertensive medications are currently or have previously been used by 80% of students with symptoms of hypertension.

Students took the following medications (the percentage of respondents who took them is indicated in parentheses): enalapril (39.3%), lisinopril (25%), bisoprolol (21.5%), nebivolol (14.4%), combination antihypertensive drugs (10.7%), metoprolol (10.7%), amlodipine (7.1%), captopril (3.6%), and indapamide (3.6%).

Note, that the total exceeds 100% because one student may have used multiple drugs or different drugs during different periods. The predominance of ACE inhibitors (enalapril and lisinopril, 64.3% in total) and modern β-blockers (bisoprolol and nebivolol, 35.7% in total) fully corresponds to current ESC/ESH 2018–2023 guidelines, which describe in detail the mechanisms of action of these drug classes, their high efficacy, safety, and preference in young patients.

It is well known that despite the continuously expanding range of antihypertensive drugs, this alone does not improve adherence. Patients (including students) may simply forget to take medications regularly or may deliberately avoid treatment, believing it is unnecessary in the absence of hypertension symptoms (e.g., headache, tachycardia, etc.), perceiving drugs as harmful chemical substances [24–28]. Our survey is fully consistent with these findings, as 32% of those taking medications reported forgetting doses either "frequently (almost every day)" or "rarely." This confirms the insufficient adherence of students to antihypertensive treatment.

Non-pharmacological approaches such as aerobic exercise, physical training, antihypertensive diet, increased sleep duration in case of deficiency, and sedative therapy (including combined sedatives containing phenobarbital such as Corvalol and valerian preparations) are used by 25% of students with elevated blood pressure. Most respondents reported awareness of target blood pressure values; however, regular medical consultations are not consistently received.

From a pharmacoeconomic perspective, drug selection is primarily determined by affordability. Students with limited financial resources more often choose inexpensive generic medications. The approximate monthly cost of therapy is presented in Figure 1.

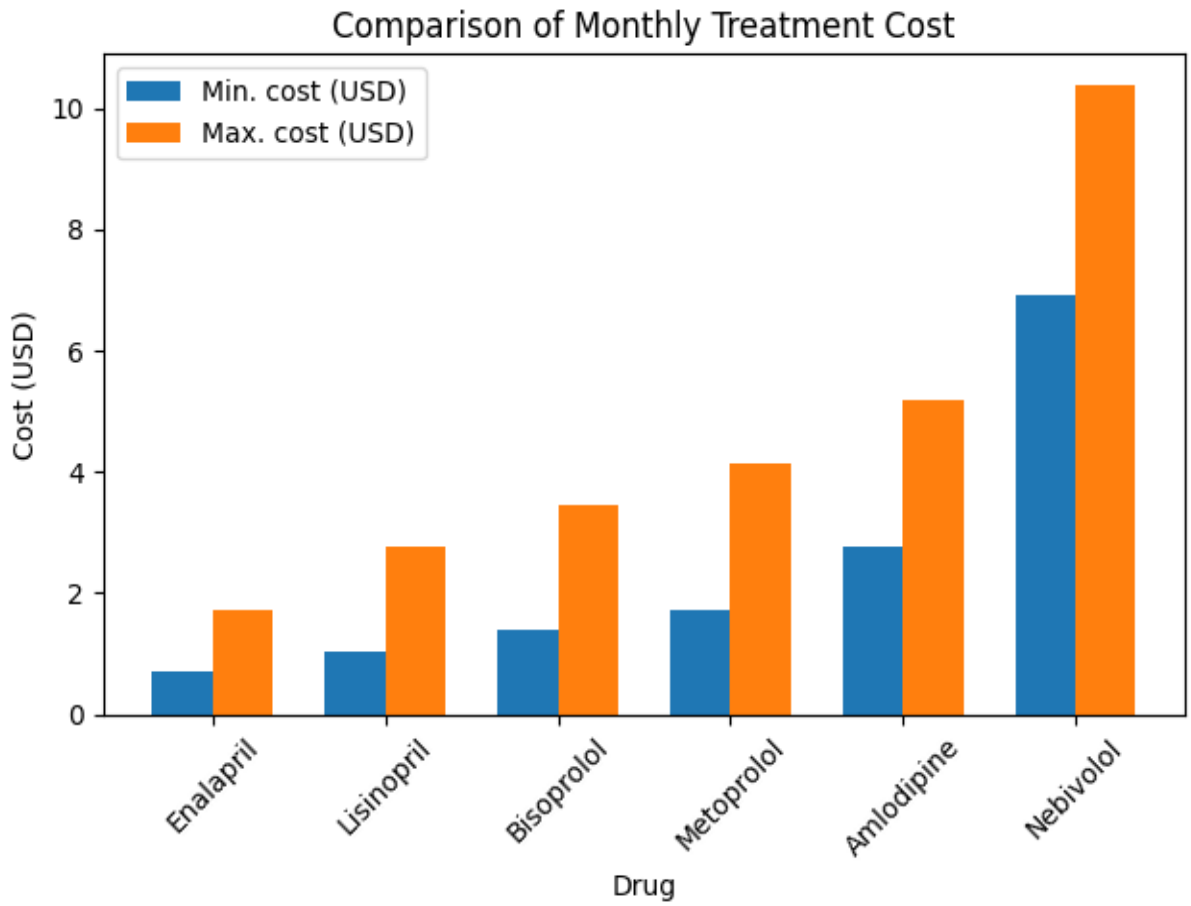

*Figure 1. Approximate monthly cost of selected antihypertensive therapy**

*Based on current pharmacy prices in state and commercial pharmacies in Grodno (converted to USD using the National Bank exchange rate as of 11.04.2026).

Note: since multiple manufacturers are present on the pharmaceutical market and drug prices vary, the average cost of all generics for each listed drug was calculated based on standard doses: bisoprolol 5 mg, enalapril 10 mg, lisinopril 10 mg, metoprolol 50 mg, amlodipine 5 mg, nebivolol 6 mg.

As shown, enalapril and lisinopril remain the most cost-effective options, which explains their leading position. Nebivolol is more expensive; however, it is likely chosen due to students' awareness of its better tolerability and additional NO-mediated vasodilatory properties. Amlodipine occupy an intermediate position both in cost and frequency of use.

It is well established that economic factors (treatment cost) are of major importance in chronic diseases requiring lifelong therapy, such as arterial hypertension. Patients tend to reduce costs by choosing cheaper drugs and avoiding multiple prescriptions; therefore, adherence is often higher with fixed-dose combination antihypertensive therapies [29–33].

The economic factor is particularly relevant for students: their limited purchasing power restricts the use of expensive original drugs, while the availability of generics allows effective therapy. This indicates that pharmacoeconomic approaches ("cost-effectiveness" and "cost-minimization") can optimize hypertension management according to patients' financial capabilities.

Despite medical education emphasizing the importance of consulting healthcare professionals, a considerable proportion of students (approximately 20%) rely on self-medication or recommendations from relatives or the internet. Blood pressure is measured infrequently (once a month or less). This highlights the need to strengthen educational interventions aimed at hypertension prevention and improving treatment adherence.

Conclusions

1. Antihypertensive drugs are used by 17.3% of medical students, mainly ACE inhibitors (enalapril, lisinopril) and β-blockers (bisoprolol, nebivolol).
2. Economic factors strongly influence treatment selection, with a predominance of low-cost generics.
3. Adherence remains low; additional preventive and educational measures are required.

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PEDAGOGICAL SCIENCES

THE FACILITATIVE ASPECT OF DEVELOPING STUDENTS' STRATEGIC COMPETENCE IN ORAL PROFESSIONAL COMMUNICATION WITHIN DISTANCE FOREIGN LANGUAGE LEARNING

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Abstract

The article provides a theoretical and methodological substantiation of the concept of digital facilitation as a key factor in developing students' strategic competence in oral professional communication within the student-centered paradigm of distance education. The study demonstrates that in the context of total digitalization, the classical model of strategic competence evolves into the concept of digital communicative flexibility. This construct integrates the speaker's ability to overcome the "screen barrier," adapt to the technical discreteness of the media channel, and flexibly leverage the multimodal tools of virtual platforms to preserve an authentic authorial voice.

To achieve the research objectives, a complex of theoretical methods was employed: comparative, systemic, definitional, and terminological analysis, alongside pedagogical modeling.

As a result of the study, the linguodidactic substance of the concept of "digital facilitation" has been revealed, and three key vectors of its implementation have been determined (psychological de-escalation, interactive decentralization, and cognitive scaffolding), which ensure the minimization of students' foreign language anxiety and the lowering of the affective filter. The author's theoretical and conceptual model has been scientifically substantiated, finding its practical reflection in a prospective complex of strategies (*The Virtual Pitch, AI-Opponent Simulations, Micro-VIVA*). These innovative formats allow shifting the focus of assessment from evaluating the final speech product, which can be compromised in the era of generative artificial intelligence, to evaluating the live process of spontaneous thinking in a foreign language, thereby ensuring the protection of academic integrity and the restoration of the student's agency. Finally, the prospects for the further transformation of the developed model into the practical domain of higher education through the creation of applied guidelines and digital case studies have been outlined.

Keywords: strategic competence, digital communicative flexibility, digital facilitation, student-centeredness, affective filter, artificial intelligence, academic integrity, distance learning.

Introduction

The dynamic evolution of the global business environment necessitates a transformation of requirements for foreign language training of future specialists in higher education. Under current socioeconomic conditions, a professional's relevance is determined not only by their academic or narrow vocational toolkit but also by a high level of intercultural interaction culture. A key component of graduates' professional capability is strategic competence in oral communication, interpreted as the ability to not merely manipulate lexicogrammatical assets flexibly, but to effectively mitigate communicative risks, overcome psycholinguistic barriers, and adapt to the changing contexts of professional dialogue. The forced integration of the distance format into the educational space of Ukraine, while ensuring the continuity and inclusiveness of higher education, has driven the large-scale use of innovative technologies. However, extensive experience in the practical application of videoconferencing platforms for synchronous classes has revealed a profound methodological paradox: the integration of digital tools into the educational process does not, by itself, guarantee the automatic development of fluent, spontaneous professional speech skills.

Modern linguodidactics notes a pronounced limitation of the technocentric approach, wherein hyperfixation on the functional capabilities of digital platforms nullifies the personal dimension of learning. An alternative to this is the student-centered educational paradigm, the conceptual core of which involves a functional transformation of the educator's role from a linear controller and transmitter of knowledge into a facilitator of the virtual communicative process. Substantiating the theoretical and methodological foundations of digital facilitation is critically essential for overcoming the phenomena of screen alienation and students' communicative passivity. The implementation of this approach allows for the revitalization of the future specialist's authentic authorial voice, guaranteeing psychological safety and strategic flexibility in their oral professional speech within distance education.

Analysis of Recent Research and Publications

The investigation into the formation of strategic competence and its specifics within the digital space lies at the intersection of linguodidactic, psychological, and technological research. The theoretical foundation for analyzing this phenomenon is provided by the classical models of M. Canale and M. Swain (Canale & Swain, 1980), where it is defined as a compensatory mechanism — the speaker's ability to employ verbal and non-verbal strategies (paraphrasing, circumlocution, requests for assistance) to overcome linguistic gaps. However, in distance learning environments, this

approach requires revision: while in a traditional classroom setting, strategic actions are aimed solely at compensating for a lack of linguistic knowledge, in a virtual environment, they are significantly complicated by the limitations of the interaction media channel itself (technical glitches, scarcity of non-verbal cues). A large-scale analysis of the impact of such virtual learning environments, conducted in a systematic literature review by L. Caprara and C. Caprara (2022), demonstrates both the powerful potential of digitalization and the urgent need to develop new interactive tools for student adaptation and support.

The issues of transforming the "authorial voice" and the specifics of academic interaction in the era of rapid generative artificial intelligence development are thoroughly investigated by F. Jiang and K. Hyland (Jiang & Hyland, 2024). Analyzing engagement markers within argumentative essayistic discourse, the authors demonstrate that the success of professional communication depends not on the flawless copying of normative AI language templates, but on the student's ability to project their own agency and confidence through language. However, these studies predominantly focus on written communication, leaving open the question of how to preserve individual style and strategic flexibility in the context of spontaneous oral online dialogue.

The technological dimension of integrating innovative tools into foreign language training is highlighted in detail in the works of R. Godwin-Jones (2024) and N. Hockly (2023). Specifically, R. Godwin-Jones analyzes the phenomenon of distributed agency in the context of generative AI implementation, demonstrating that virtual ecosystems are capable of ensuring a high level of material authenticity while simultaneously requiring a greater degree of digital autonomy from students. At the same time, immersion into digital platforms often induces profound cognitive and psycho-emotional strain. The nature of this phenomenon is fundamentally disclosed in the work of J. N. Bailenson (2021), who theoretically substantiated the non-verbal overload ("Zoom fatigue") that arises from the disruption of natural communication dynamics during the prolonged use of videoconferencing.

In turn, N. Hockly (2023) focuses her research on the challenges of utilizing artificial intelligence and the concept of social presence. She argues that the "screen barrier" effect often induces apathy and a tendency toward self-isolation among students (the "culture of turned-off cameras"), which significantly raises the "affective filter" — a psychological barrier (fear, inhibition, anxiety) that, according to S. Krashen's classical theory (Krashen, 1982), blocks successful language acquisition. Overcoming this issue is possible through a radical shift in the educator's role — moving away from linear control toward organizing group interaction. The specifics of such a transformation in higher education are highlighted by G. Thomas and S. Thorpe (2019), who, in their review of online facilitation practices, demonstrate that successful work in virtual groups requires specific skills from the educator in managing group dynamics and decentralizing the educational process.

Within the Ukrainian scientific discourse, the vector of systemic digital transformation in higher education has been established by the works of N. V. Morze and her co-authors (Morze et al., 2020). The researchers describe in detail the structure of the educator's digital competence profile, emphasizing that a modern teacher must possess not only an instrumental level (the ability to use services) but also a methodological one — the ability to create an interactive environment that stimulates critical thinking. The philosophical and methodological foundation for this transformation is provided by the works of V. G. Kremen (Kremen, 2023). Substantiating the philosophy of student-centeredness within the system of modern values, the academician demonstrates that the transition to innovative learning models must be grounded in respect for the student's personality, the development of their autonomy, and a partnership-based interaction where the teacher acts not as an authoritarian transmitter of knowledge, but as a facilitator.

Thus, the study of the specifics of strategic competence formation in a virtual environment requires a synergy of linguodidactic, psychological, and instrumental scientific approaches, which will allow for the adaptation of the classical model of compensatory strategies to the challenges of the modern high-tech educational space.

Objective and tasks

The objective of the article is to provide a theoretical and methodological substantiation of the concept of digital facilitation as a key factor in developing students' strategic competence in oral professional communication, and to design the architecture of its practical implementation within the student-centered paradigm of distance foreign language learning. To achieve this objective, a series of sequential research tasks encompassing both fundamental and applied aspects of the studied phenomenon has been outlined. First and foremost, it involves conducting a profound theoretical analysis of the essence and component structure of strategic competence in oral professional communication within the specific dimension of the virtual educational space, factoring in the challenges of technical communication discreteness. The next task entails disclosing the linguodidactic substance of the digital facilitation concept and determining the vectors of virtual pedagogical charisma's impact on minimizing foreign language anxiety and de-escalating students' affective filters in a synchronous online format. Finally, the study aims to scientifically substantiate and model a prospective complex of facilitative strategies, including scenario-based learning and AI-powered voice simulations, while clearly outlining the trajectory for their further experimental verification in higher education institutions.

Research methods

To solve the defined tasks and form a coherent theoretical concept, a complex of complementary methods of the theoretical research level was employed, integrated into the general methodological structure of the work. A leading role in substantiating the concept is occupied by comparative and systemic analysis of scientific linguodidactic, psychological, and methodological

literature, aimed at a critical revision of existing approaches to understanding strategic competence and clarifying the essential characteristics of the conceptual and categorical apparatus in the context of educational digitalization. For a distinct terminological isolation of new pedagogical phenomena, definitional and terminological analysis was applied, which allowed for specifying the substance of the concepts "digital facilitation" and "virtual pedagogical charisma" directly within the context of students' foreign language training. The direct construction of the predictive model was carried out based on the methods of pedagogical modeling and design, through which the theoretical architecture of facilitative learning was developed and algorithms for the interactive engagement of educational process subjects in the virtual space were created. On a theoretical level, through the methods of extrapolation and scientific forecasting, a hypothetical outline of the potential outcomes of the proposed strategies' application was provided, along with the analytical identification and preemptive analysis of possible communicative risk zones and psycholinguistic barriers.

Results and Discussion

In classical linguodidactics, beginning with the fundamental works of M. Canale and M. Swain (Canale & Swain, 1980), strategic competence was traditionally viewed through the prism of a compensatory function — as the speaker's ability to minimize a deficit in linguistic knowledge using verbal and non-verbal substitutes. However, the process of transferring this model into the domain of the virtual educational space requires a significant rethinking of its architecture, given that the nature of communicative obstacles changes radically online. Drawing upon K. Hyland's research (Jiang & Hyland, 2024) on the transformation of the authorial voice and N. Hockly's concept of social presence (Hockly, 2023), we argue that in distance education, strategic competence evolves from purely linguistic compensation to a higher level — digital communicative flexibility. Based on the integration of psycholinguistic and student-centered approaches, we have developed a predictive three-component structure of this competence, with each element adapted to the conditions of a computer-mediated environment.

The first constituent of this structure is the psycholinguistic component, focused on the speaker's mobility and self-regulation. It is based on S. Krashen's affective filter theory (Krashen, 1982) and J. Bailenson's contemporary research on cognitive overload during videoconferencing (Bailenson, 2021). This component implies the student's ability to overcome a specific screen barrier and operate under time constraints. We contend that in the digital space, spontaneous speech is complicated not only by psychological fear but also by the purely technical phenomenon of audio delay (latency), which, as Bailenson aptly notes, disrupts the natural prosodic characteristics of speech. Consequently, our authorial interpretation of the student's strategic activity in this context lies in the ability to maintain mental resilience and speech dynamics even during forced technical pauses, transforming connectivity glitches from a panic factor into a natural element of communication.

The second element is the instrumental-technological component, which we define as the multimodal enhancement of the speech act. In the process of its substantiation, we drew upon R. Godwin-Jones's theory of multimodality (Godwin-Jones, 2024). While in a traditional classroom non-verbal strategies are limited to natural gesturing, in a virtual classroom — where the webcam frame restricts bodily expression — there arises a need for the artificial digital extension of speech. Our perspective on solving this issue is that the student must learn to consciously utilize platform tools (screen sharing, interactive elements of the Miro board, or pinning key points in the chat) as external cognitive scaffolds (*scaffolding*) that support oral argumentation, preventing the speech act from breaking down due to a lack of vocabulary.

The third, socio-presentational component, is responsible for the projection of the speaker's professional "self" within the digital space. The theoretical foundation for understanding the challenges of this element is provided by J. N. Bailenson's concept regarding the deficit of non-verbal information in a virtual environment, which provokes the psycho-emotional disengagement of communication participants (Bailenson, 2021). In turn, the linguodidactic toolkit for overcoming this barrier draws upon the research of F. Jiang and K. Hyland (Jiang & Hyland, 2024) in terms of using engagement markers to construct a compelling "authorial voice." This component defines the ability to transmit confidence and expert status in a foreign language through a restricted media channel. We contend that under conditions of virtual alienation, the student must compensate for the lack of physical presence using accessible interactive means, namely: accented intonation, clear structural framing of the utterance, the use of rhetorical markers of interaction, and the ability to dynamically manage the virtual audience's attention.

Understanding this three-component structure leads us to the conclusion that the traditional model of linear control along the "teacher-student" vector is completely ineffective online, as it only reinforces the verbal passivity of the audience. Consequently, there is an urgent need to define a fundamentally new role for the educator. The phenomenon of facilitation within a digital language environment acquires a specific, technologically mediated substance, which is thoroughly analyzed in the comparative studies of G. Thomas and S. Thorpe (Thomas & Thorpe, 2019) regarding the specifics of managing online groups. Drawing upon V. G. Kremen's philosophical concept of student-centeredness (Kremen, 2023) and N. V. Morze's teacher digital competence profile model (Morze et al., 2020), we define digital facilitation as a systemic, empathically grounded activity of the educator aimed at optimizing the virtual communicative space, reducing students' psychological strain, and creating conditions for their maximum speech autonomy and activity.

Drawing upon the aforementioned approaches and our own experience in modeling online classes, we distinguish three key vectors through which charismatic facilitation ensures the development of students' strategic competence.

The first is the vector of psychological de-escalation, aimed at lowering the affective filter. Drawing

upon S. Krashen's classical concept (Krashen, 1982), we contend that under conditions of digital interaction, the facilitator must use their behavior to consciously neutralize the destructive "spotlight effect" (*Spotlight Effect*), where the student feels under constant psychological pressure from a turned-on camera. As G. Thomas and S. Thorpe (Thomas & Thorpe, 2019) note, successful management of online group dynamics involves creating a safe communicative space. Through the mechanisms of emotional contagion and empathy, the educator legitimizes speech risk, shifting the student's focus from the fear of making a grammatical error to the successful achievement of the ultimate communicative or business goal.

The second vector — interactive decentralization — directly implements N. Hockly's methodological recommendations (Hockly, 2023) on overcoming the passive "cameras-off culture." Our vision of this strategy lies in radically minimizing the instructor's own verbal presence (Teacher Talking Time) in favor of autonomous student interaction (Student-to-Student). Under this approach, breakout rooms are utilized not as a tool for the mechanical and isolated execution of exercises, but as an artificially engineered space of controlled communicative risk, where students are left face-to-face with a speech problem and are compelled to independently employ compensatory strategies.

The third vector is defined as cognitive scaffolding, which, within the context of contemporary digital ecosystems, is thoroughly investigated in the works of R. Godwin-Jones (Godwin-Jones, 2024) and the studies of L. Caprara and C. Caprara (Caprara & Caprara, 2022) regarding the specifics of virtual learning space organization. Within this vector, the facilitator does not merely observe but flexibly structures the digital environment of the class. Our reasoning is that the instructor must provide students with dynamic mind maps, visual interactive templates, and conceptual frames. Such tools serve as reliable navigational scaffolds during spontaneous monologue or discussion, helping each student overcome cognitive overload and confidently project their authorial voice into digital discourse, drawing upon F. Jiang and K. Hyland's models of language engagement (Jiang & Hyland, 2024).

Based on a critical analysis of existing linguodidactic approaches and taking into account the specifics of psychological barriers in the virtual environment, we have developed and scientifically substantiated an authorial predictive model of digital facilitation. Our vision rests on the conviction that the development of strategic competence is possible only through the transformation of the digital space from a place of passive content consumption into a space of controlled communicative risk. Within the framework of this concept, we propose an authorial complex of prospective practical strategies aimed at stimulating students' spontaneous speech and integrating their agency and authentic authorial voice.

The first tool of this model is the innovative pitching strategy (*The Virtual Pitch*), which functions as a scenario-based role-play modeling of a real business environment. In contrast to the traditional listening to pre-prepared reports, which online inevitably transforms into a monotonous and mechanical reading of text from the screen, we propose a radical renovation of this format. According to our concept, the student is placed within a strict time limit lasting no more than 180 seconds, during which they must present a business idea or propose a solution to a complex economic case. The primary didactic condition here is maintaining the audience's attention solely through the restricted space of the webcam. The instructor, acting as a facilitator, consciously decentralizes this process by delegating their authority to the group: other students act as critical investors, opponents, or auditors. We firmly believe that strategic competence and verbal flexibility are formed not during the recitation of the main monologue, but precisely during the unpredictable, interactive Q&A session. Since the colleagues' questions cannot be anticipated, the student is compelled to instantly deploy the entire arsenal of compensatory mechanisms, adapting their lexical repertoire on the fly and completely abandoning the use of pre-written scripts.

The next step in expanding our model is the integration of the AI-Opponent Simulations strategy, where generative artificial intelligence functions as a flexible cognitive scaffold. The current stage of technological development allows the utilization of AI in linguodidactics to expand far beyond the mere generation or translation of texts. We propose utilizing artificial intelligence as a dynamic, interactive speech simulator. According to our concept, prior to engaging in an open, real-time group discussion, the student undergoes an obligatory stage of autonomous speech preparation by interacting with a voice-based AI agent configured for the role of a demanding foreign partner or a tough opponent. Our position is grounded in the fact that such a simulation fulfills the vital function of a safe microenvironment. The opportunity to make mistakes without the fear of losing social or professional status in front of colleagues significantly reduces foreign language anxiety and de-escalates the affective filter. Concurrently, this intensively develops strategic competence and verbal flexibility, as generative AI constructs authentic, non-template remarks, compelling the student to promptly mobilize their linguistic resources under conditions closely resembling real-world intercultural negotiations.

The logical culmination of the proposed architecture is our custom-designed assessment format named *Micro-VIVA*, which entails an expert defense of the generated speech product. The massive utilization of AI translators and text generators by students during distance learning demands a complete overhaul of the classical control system. We argue that evaluating a finished written text or a pre-recorded monologue online has lost its didactic purpose today, as these products can be entirely compromised by third-party technologies. In contrast, our proposed format represents a brief, charismatically moderated by the teacher oral defense of one's own project or analytical essay. By posing several challenging or clarifying questions regarding the internal logic of the utterance and the economic background of the work, the teacher-facilitator compels the

student to defend their position here and now. Our rationale is that such a format successfully shifts the focus of pedagogical attention from evaluating the final artifact to the very process of critical thinking in a foreign language. This not only reliably safeguards academic integrity in the era of digitalization but also stimulates the student to demonstrate genuine, confident mastery of communicative strategies and the ability to argumentatively assert their professional "self" in real time.

Prospects for further research

Since this article is of a theoretical and conceptual nature (*conceptual research*), the three-component facilitative model we have developed serves as a baseline scientific and methodological architecture for updating the substance of students' foreign language training within the digital space. It establishes the necessary theoretical foundation for rethinking the interaction between educational process participants under distance learning conditions and abandoning ineffective linear models of control.

Prospects for further exploration in this direction are primarily associated with the design and implementation into higher education practice of applied methodological recommendations, syllabi, and digital case studies that integrate interactive learning scenarios adapted for the use of artificial intelligence tools. An equally vital vector is the formulation of practical guidelines and micro-scenarios to develop digital facilitation skills in educators themselves, which will help effectively overcome the "screen barrier" and students' cognitive overload directly during synchronous online classes. Furthermore, further theoretical study is required to analyze how exactly the deployment of the proposed strategies influences the level of students' communicative confidence and the formation of their individual "authorial voice" within virtual professional discourse.

Consequently, future scholarly inquiry will be directed toward the logical transformation of the proposed theoretical model into a practical dimension — namely, the creation of a comprehensive methodological framework for optimizing foreign language education within contemporary digital learning ecosystems.

Conclusions

As a result of the conducted theoretical and methodological research, the specifics of students' foreign language training within the contemporary digital space have been comprehensively re-evaluated. The analysis of linguodidactic and psycholinguistic sources has substantiated that under conditions of mass educational digitalization, the classical understanding of strategic competence as a purely linguistic compensatory mechanism requires expansion, evolving into the concept of digital communicative flexibility. This construct integrates not only the ability to minimize lexical and grammatical deficits but also the speaker's readiness to promptly overcome the specific screen barrier, adapt to the technical limitations of the media channel, and synchronize oral speech with the multimodal tools of virtual platforms to preserve their authentic authorial voice.

In view of this, the traditional technocentric approach to teaching gives way to a student-centered paradigm, at the core of which lies the concept of digital facilitation. It defines a fundamentally new role for the educator, who transforms from a linear controller into a moderator and psychological driver of virtual interaction. The key instrument of such transformation is the implementation of the facilitative approach, which — through the vectors of psychological de-escalation, interactive communication decentralization, and cognitive scaffolding — allows for minimizing students' foreign language anxiety, dismantling the "spotlight effect," and legitimizing speech risk for the sake of achieving professional goals.

The theoretical and conceptual model proposed within this study finds its practical reflection in a complex of strategies that includes the formats of innovative pitching, speech simulations with artificial intelligence systems, and the *Micro-VIVA* oral defense of performance outcomes. These formats allow for shifting the focus from controlling and evaluating the final text — which, in the era of generative AI, is easily susceptible to falsification — to assessing the actual process of spontaneous thinking in a foreign language, thereby restoring students' agency and safeguarding academic integrity. Prospects for further exploration in this direction are associated with the logical transfer of the developed model into the practical dimension of higher education through the creation of applied methodological guidelines, digital case studies, and syllabi adapted to the conditions of contemporary learning ecosystems.

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APPLICATION OF THE PROBLEM-BASED LEARNING METHOD IN TEACHING AMINO ACIDS WITHIN A BILINGUAL LEARNING CONTEXT

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Abstract

The teaching of amino acids requires an instructional approach that helps students understand both the chemical structure of these compounds and their biological significance. Amino acids are not only organic molecules containing amino and carboxyl functional groups, but also the structural units of proteins, enzymes, hormones, and many biologically active substances. For this reason, the topic creates a natural bridge between chemistry, biology, medicine, nutrition, and biotechnology. However, students often face difficulties in understanding the amphoteric nature of amino acids, peptide bond formation, zwitterionic structure, and the relationship between molecular structure and biological function.

This article examines the application of the problem-based learning method in teaching amino acids within a bilingual learning context. Problem-based learning supports students' active participation, critical thinking, research skills, and collaborative learning by engaging them in real-life problem situations. In a bilingual learning environment, chemical concepts are explained through both the native language and a second language, usually English. This approach helps students develop subject knowledge and scientific language competence at the same time. The article proposes a methodological model for teaching amino acids through bilingual problem-based activities, including problem situations, group research, concept mapping, scientific vocabulary work, molecular modeling, and presentation tasks. The proposed approach may contribute to deeper conceptual understanding, better communication skills, and the formation of interdisciplinary scientific thinking among students.

Keywords: amino acids, problem-based learning, bilingual education, chemistry teaching, CLIL, scientific literacy, active learning.

INTRODUCTION

Modern chemistry education requires methods that move students beyond mechanical memorization and direct them toward inquiry, explanation, comparison, and application of knowledge. The topic of amino acids is especially suitable for this purpose because it combines several important scientific ideas: organic functional groups, molecular structure, acid-base properties, protein formation, biological function, and practical applications in medicine and nutrition. In traditional teaching, this topic is often presented mainly through definitions, formulas, and classifications. As a result, students may memorize the general formula of amino acids without understanding why these compounds are biologically significant or how their structure determines their properties [1].

Problem-based learning offers a more dynamic way of teaching this topic. In this approach, the lesson begins not with ready-made theoretical information, but with a real or simulated problem. For example, students may be asked why a lack of essential amino acids affects human growth, why proteins lose their function under certain conditions, or how peptide bonds are formed in biological systems. Such questions encourage students to search for information, discuss hypotheses, analyze molecular models, and connect chemistry with real life. In recent years, bilingual education and Content and Language Integrated Learning have also gained importance in science education. In a bilingual chemistry lesson, students learn scientific concepts through two languages. This is important because many scientific terms used in chemistry, biology, medicine, and biotechnology are internationally shared through English. A bilingual approach helps students understand both the scientific meaning and the linguistic structure of key concepts such as amino acid, peptide bond, carboxyl group, amino group, protein, enzyme, and zwitterion. Therefore, the integration of problem-based learning and bilingual teaching can create a productive learning environment. It allows students to solve scientific problems, develop chemical knowledge, and improve their academic language skills at the same time[2-4].

RELEVANCE OF THE RESEARCH

The relevance of this research is connected with the growing need to modernize chemistry teaching methods. In contemporary education, students are expected not only to know chemical concepts, but also to use them in real situations, explain natural processes, work with scientific information, and communicate their ideas clearly. Amino acids are an important topic in this regard because they have both theoretical and practical value. They are studied in organic chemistry,

biochemistry, biology, medicine, food science, and biotechnology. The problem is that many students perceive amino acids as abstract chemical formulas. They may know that amino acids contain amino and carboxyl groups, but they do not always understand how these groups influence chemical behavior or why amino acids are essential for protein synthesis. In addition, students may have difficulty using scientific terminology correctly, especially when the topic is studied in a second language.

The application of problem-based learning in a bilingual context can help overcome these difficulties. This approach makes the learning process more meaningful by connecting chemical concepts with real-life problems and scientific communication. It may increase students' engagement, motivation, critical thinking, and problem-solving capacity while also supporting the development of academic language competence.

PURPOSE OF THE RESEARCH

The main purpose of this article is to analyze the methodological possibilities of applying the problem-based learning method in teaching amino acids within a bilingual learning context. The research also aims to determine how bilingual instruction can support students' understanding of chemical concepts and their ability to use scientific terminology appropriately.

The specific objectives are:

1. To explain the pedagogical value of problem-based learning in chemistry education.
2. To determine the role of bilingual learning in developing students' scientific language competence.
3. To show how amino acids can be taught through real-life problem situations.
4. To propose a lesson model based on the integration of PBL and bilingual instruction.
5. To identify the expected educational outcomes of this approach.

LITERATURE REVIEW

Problem-based learning has been widely discussed as an active learning strategy that places students at the center of the educational process. Instead of receiving information passively, students analyze a problem, formulate questions, search for explanations, test ideas, and present solutions. In chemistry education, this method is valuable because many chemical concepts require logical reasoning, interpretation of evidence, and connection between theory and practice. Amino acids have also been used in problem-based and biochemistry-oriented teaching models. Biochemical content can be effectively taught through inquiry and dialogue-based learning because amino acids, proteins, enzymes, and metabolic processes are connected with real-life health, nutrition, and biotechnology problems. This makes amino acids a suitable topic for developing students' interdisciplinary thinking.

Bilingual and CLIL-based instruction has another important role in chemistry education. CLIL means that students learn a subject through an additional language, developing both content knowledge and language competence. In chemistry, language is especially important because students must understand terms, symbols, formulas, reaction schemes, and scientific explanations. If bilingual instruction is planned carefully, students can develop stronger scientific communication skills and more confident use of international terminology [5-8].

METHODOLOGY

The article is based on a theoretical-methodological analysis of problem-based learning and bilingual teaching in chemistry education. The proposed model can be applied in secondary school chemistry lessons, introductory organic chemistry courses, or interdisciplinary chemistry-biology classes. The teaching process may be organized in several stages: creating a problem situation, preparing bilingual vocabulary, organizing group research, using molecular modeling, conducting discussion, and reflecting on learning outcomes. At the beginning of the lesson, the teacher presents a real-life problem related to amino acids. For example, students may discuss why a teenager who follows an unbalanced diet for a long time may experience weakness, poor concentration, and slow recovery after illness. This problem encourages students to think about the biological role of amino acids, essential amino acids, proteins, enzymes, and nutrition. Before the main discussion, students work with key terms in two languages. This stage helps them understand the scientific vocabulary needed for analysis and discussion. After vocabulary preparation, students work in small groups and investigate different aspects of the problem, such as the structure of amino acids, amphoteric properties, peptide bond formation, essential amino acids, and applications in medicine or biotechnology.

Table 1.

Bilingual terminology for teaching amino acids

Native language term	English term
Amin turşusu	Amino acid
Amin qrupu	Amino group
Karboksil qrupu	Carboxyl group
Peptid rabitəsi	Peptide bond
Zülal	Protein
Əvəzolunmayan amin turşuları	Essential amino acids
Amfoterlik	Amphoteric property
Zwitterion	Zwitterion

This table supports the correct use of scientific terms in both the native language and English. It helps students participate in discussion and present their explanations more confidently.

Table 2.

Group research tasks in a PBL-based amino acids lesson

Group	Research task
Group 1	Chemical structure of amino acids
Group 2	Acid-base and amphoteric properties
Group 3	Peptide bond formation
Group 4	Essential amino acids and nutrition
Group 5	Amino acids in medicine and biotechnology

The distribution of tasks allows students to analyze the problem from different scientific perspectives and then synthesize their findings through group discussion.

Table 3.

Proposed lesson model

Lesson stage	Teacher activity	Student activity	Expected result
Motivation	Presents a real-life nutrition problem	Express initial ideas	Interest and problem awareness
Problem formulation	Asks guiding questions	Defines research questions	Development of inquiry skills
Vocabulary work	Explains key terms bilingually	Creates bilingual glossary	Scientific language development
Group research	Guides students	Searches, discusses, compares	Collaborative learning
Modeling	Provides structural formulas or models	Builds or draws amino acid structures	Visual understanding
Discussion	Organizes debate	Explains solutions	Critical thinking
Reflection	Gives summary questions	Evaluates learning	Consolidation of knowledge

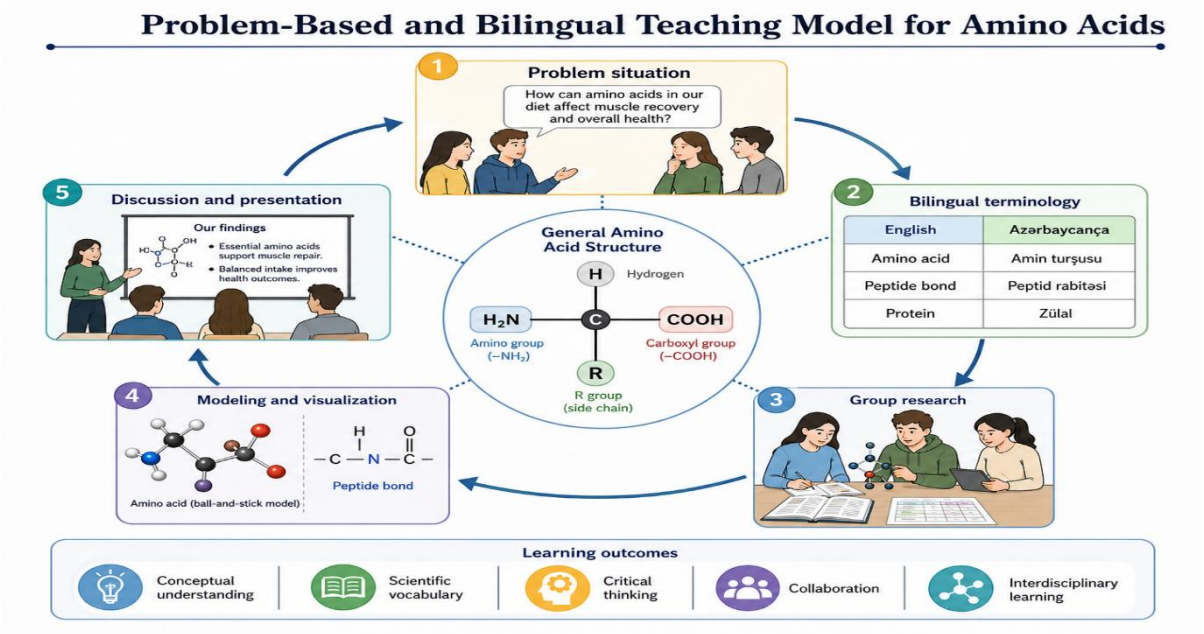

Figure 1. Problem-Based and Bilingual Teaching Model for Amino Acids

The figure illustrates a problem-based and bilingual teaching model for the topic of amino acids. It shows how the lesson begins with a real-life problem situation, continues with bilingual terminology work, group research, molecular modeling, discussion, and presentation. The model supports students' conceptual understanding, scientific vocabulary, critical thinking, collaboration, and interdisciplinary learning.

PROPOSED PROBLEM-BASED LESSON MODEL FOR TEACHING AMINO ACIDS

The proposed lesson model is based on the integration of problem-based learning and bilingual instruction. Its main purpose is to help students understand amino acids not only as organic compounds, but also as biologically important molecules connected with proteins, enzymes, nutrition, medicine, and biotechnology. In this model, the learning process begins with a real-life problem situation and gradually moves toward scientific explanation, bilingual terminology

work, group research, molecular modeling, discussion, presentation, and reflection.

At the first stage, the teacher presents a problem situation related to health and nutrition. For example, students may be asked to explain why balanced nutrition requires essential amino acids, how amino acid deficiency may affect the human body, or why proteins are important for growth and recovery. This situation encourages students to think, ask questions, and make initial assumptions before receiving ready-made theoretical information. As a result, the lesson becomes more inquiry-oriented and meaningful.

At the second stage, bilingual terminology is introduced. Students work with key terms in both their native language and English, such as *amino acid, amino group, carboxyl group, peptide bond, protein, enzyme, essential amino acids,* and *zwitterion*. This stage helps students understand the scientific content and use international terminology correctly. It also supports the development of academic language skills, which are important for reading scientific texts and participating in scientific communication. At the third stage, students are divided into small groups and each group investigates a specific aspect of the problem. One group may study the general structure of amino acids, another group may analyze their amphoteric properties, while other groups may focus on peptide bond formation, essential amino acids in nutrition, or the role of amino acids in medicine and biotechnology. This division of tasks allows students to examine the topic from different perspectives and then combine their findings into a broader scientific explanation.

At the fourth stage, molecular modeling and visualization are used. Students draw the general structure of amino acids, build simple molecular models, identify the amino and carboxyl groups, and explain how peptide bonds are formed. Visual and model-based activities help students move from abstract formulas to concrete understanding. This is especially important because many students find it difficult to imagine the spatial structure of organic molecules only through written formulas.

At the fifth stage, students present their findings and discuss the problem collectively. During the presentation, they explain the relationship between the chemical structure of amino acids and their biological functions. They may also compare different amino acids, discuss the importance of essential amino acids, and explain why proteins are necessary for the human body. The teacher guides the discussion, corrects misconceptions, and helps students formulate scientifically accurate conclusions.

The final stage is reflection. Students evaluate what they have learned, identify which concepts were difficult, and explain how the bilingual terminology helped them understand the topic. Reflection may be organized through short written answers, oral discussion, concept maps, or exit tickets. This stage strengthens conceptual understanding and allows the teacher to assess students' progress [10-15].

Table 4.

Expected learning outcomes of the proposed model

Component of the model	Expected learning outcome
Problem situation	Students connect amino acids with real-life health, nutrition, and biological processes.
Bilingual terminology	Students learn and use key scientific terms in both their native language and English.
Group research	Students develop inquiry, comparison, information analysis, and collaborative learning skills.
Molecular modeling	Students understand the general structure of amino acids, functional groups, and peptide bond formation more clearly.
Discussion and presentation	Students improve scientific communication, argumentation, and presentation skills.
Reflection	Students evaluate their learning progress and identify the main scientific conclusions of the lesson.

The expected outcomes of the proposed model show that the teaching of amino acids should not be limited to memorizing formulas and definitions. Through problem-based and bilingual activities, students can develop a deeper understanding of the chemical and biological significance of amino acids. At the same time, they improve their ability to use scientific vocabulary, explain molecular structures, and connect chemistry with real-life situations.

ASSESSMENT CRITERIA

The effectiveness of the proposed lesson model can be evaluated through both formative and summative assessment methods. During the lesson, the teacher may observe students' participation in group work, their use of bilingual terminology, their ability to explain molecular structures, and the quality of their oral presentations. Written worksheets, concept maps, short reflections, and vocabulary tasks may also be used to assess students' understanding.

Assessment should focus not only on the final answer, but also on the learning process. In a problem-based lesson, students' ability to ask questions, search for information, compare ideas, cooperate with group members, and justify their conclusions is especially important. In a bilingual context, attention should also be paid to students' correct use of scientific terms in both languages.

Table 5.

Assessment rubric for the proposed lesson model

Criterion	High level	Medium level	Low level
Conceptual understanding	Explains the structure, properties, and biological role of amino acids clearly and accurately.	Explains the main ideas, but some details are incomplete or partially correct.	Gives fragmented, unclear, or incorrect explanations.
Use of bilingual terminology	Correctly uses key terms in both the native language and English.	Uses some scientific terms correctly, but makes occasional mistakes.	Has difficulty understanding and using bilingual terminology.
Group participation	Actively contributes to group research, discussion, and problem solving.	Participates in group work with some support from peers or teacher.	Shows limited participation and weak involvement in group tasks.
Molecular modeling	Correctly identifies functional groups and explains peptide bond formation using models or diagrams.	Identifies some structural elements, but explanation is not fully developed.	Has difficulty interpreting molecular models and structural formulas.
Presentation skills	Presents findings clearly, logically, and scientifically.	Presents the main ideas, but organization or explanation needs improvement.	Presentation is unclear, incomplete, or poorly connected with the topic.
Reflection	Clearly evaluates learning outcomes and identifies key conclusions.	Gives a general reflection, but does not fully explain learning progress.	Gives very limited or superficial reflection.

This rubric can help teachers evaluate students' learning more objectively. It also makes the assessment process transparent for students, because they can see which skills and competencies are expected from them. The rubric may be adapted depending on students' age, language level, and the complexity of the lesson.

LIMITATIONS OF THE STUDY

Although the proposed model has practical and methodological value, the article is mainly theoretical in nature. The model is designed as a suggested instructional framework and has not yet been tested through a large-scale experimental study. Therefore, its effectiveness may depend on several factors, including students' prior knowledge, their English language level, the teacher's experience with problem-based learning, and the availability of visual or digital teaching materials. Another limitation is related to the bilingual component of the model. If students have a weak command of English, excessive use of foreign terminology may create additional difficulty. For this reason, bilingual instruction should be introduced gradually and supported with visual aids, glossaries, examples, and teacher guidance. The aim of bilingual terminology work should be to support scientific understanding, not to replace conceptual learning with mechanical memorization of terms [16-18].

FUTURE RESEARCH DIRECTIONS

Future research may focus on the experimental application of the proposed model in real classroom conditions. It would be useful to compare the learning outcomes of students taught through traditional methods with those taught through problem-based and bilingual instruction. Such research may include pre-tests and post-tests, student questionnaires, teacher observations, and analysis of students' written and oral explanations. Further studies may also examine how bilingual terminology work influences students' scientific vocabulary, reading comprehension, and ability to explain biochemical concepts in English. In addition, future research may investigate the role of digital tools, molecular modeling software, virtual laboratories, and interactive simulations in strengthening the proposed model. This would make it possible to develop a more comprehensive and technology-supported approach to teaching amino acids in modern chemistry education.

DISCUSSION

The integration of problem-based learning and bilingual teaching has several pedagogical advantages. First, it increases students' cognitive activity. When students begin the lesson with a problem, they become more motivated to search for explanations. Amino acids are not presented as isolated formulas, but as compounds that have real biological and practical significance. Second, this approach supports interdisciplinary learning. Amino acids are studied in chemistry as organic compounds, in biology as protein-building units, in medicine as biologically active substances, and in nutrition as essential components of food. Through PBL, students see that scientific knowledge is not divided into separate fragments, but works as an interconnected system.

Third, the bilingual context develops students' academic language. Chemistry has a specific language that includes symbols, formulas, structural terms, and conceptual explanations. When students learn terms in both their native language and English, they become better prepared to read scientific texts, participate in international academic communication, and understand global scientific resources. However, the approach also requires careful planning. The teacher should not overload students with too many English terms at once. Bilingual instruction must support understanding, not create additional difficulty. For this reason, vocabulary lists, visual materials, concept maps, and guided questions are necessary.

SCIENTIFIC NOVELTY OF THE RESEARCH

The scientific novelty of this article lies in the integration of three important components in teaching

amino acids: problem-based learning, bilingual learning, and interdisciplinary chemistry-biology integration. The proposed model differs from traditional teaching because it does not present amino acids only as a theoretical organic chemistry topic. Instead, it interprets amino acids as a problem-centered, language-supported, and interdisciplinary learning unit. This approach creates a methodological basis for developing students' conceptual understanding, scientific communication, and research-oriented thinking. It also allows teachers to combine chemical theory with practical questions related to health, nutrition, biotechnology, and environmental awareness.

PRACTICAL SIGNIFICANCE

The practical significance of this article lies in the possibility of applying the proposed problem-based and bilingual teaching model in different educational contexts. The model can be used by chemistry teachers, biology teachers, and university instructors who prepare future teachers in the field of science education. Since the topic of amino acids is closely connected with chemistry, biology, medicine, nutrition, and biotechnology, the proposed approach creates favorable conditions for interdisciplinary teaching and for linking theoretical knowledge with real-life situations.

One of the main practical advantages of the model is that it helps teachers organize the lesson not only around definitions and formulas, but also around meaningful scientific problems. For example, students may be asked to explain why essential amino acids are necessary for the human body, how protein deficiency affects health, or why the structure of amino acids determines their biological function. Such problem situations make the learning process more active and purposeful. Instead of memorizing information passively, students investigate, compare, discuss, and present their conclusions. This can increase their motivation, critical thinking, and ability to apply chemical knowledge in practical contexts. The proposed model may also be useful for preparing lesson plans, seminar materials, bilingual worksheets, group research tasks, concept maps, and interactive classroom activities. Teachers can use the model as a methodological framework when planning lessons on amino acids, proteins, enzymes, nutrition, or related biochemical topics. In bilingual classes, the model supports the simultaneous development of subject knowledge and scientific language competence. Students learn key terms such as *amino acid, amino group, carboxyl group, peptide bond, protein, enzyme, zwitterion,* and *essential amino acids* in both their native language and English. This helps them read scientific texts more confidently, use international terminology correctly, and participate in academic discussions.

Another practical value of the model is its flexibility. Teachers can adapt it according to the age, language level, and scientific preparation of students. In lower grades, the content may be simplified and focused mainly on amino acids as building blocks of proteins and important components of food. At this level, visual materials, food examples, simple molecular models, and short bilingual vocabulary tasks may be more effective. In higher grades or university courses, the model can be expanded to include more complex concepts such as zwitterionic structure, amphoteric properties, peptide bond formation, isoelectric point, protein structure, enzyme activity, and biochemical functions. Thus, the same methodological model can be applied at different levels with appropriate modifications. The model is also practically important for developing students' research and communication skills. During group work, students can investigate different aspects of the topic, prepare short presentations, compare scientific sources, create bilingual glossaries, and explain molecular structures through models or diagrams. These activities help students form not only chemical knowledge, but also collaboration, problem-solving, scientific reasoning, and presentation skills. Such competencies are especially important in modern education, where students are expected to understand scientific information and communicate it clearly.

In teacher education programs, the proposed model can be used as an example of how problem-based learning and bilingual instruction may be integrated into chemistry teaching. Future teachers can analyze the lesson structure, design their own problem situations, prepare bilingual terminology lists, and develop assessment rubrics for student performance. This gives them practical experience in planning learner-centered, interdisciplinary, and language-supported chemistry lessons.

Therefore, the practical significance of the article is that it offers a usable methodological model for improving the teaching of amino acids. The model can support teachers in making chemistry lessons more interactive, interdisciplinary, and connected with real life. At the same time, it helps students develop deeper conceptual understanding, scientific vocabulary, academic communication, and independent thinking skills.

CONCLUSION

The teaching of amino acids becomes more effective when students are involved in active inquiry, real-life problem solving, and scientific discussion. Problem-based learning creates conditions for students to understand not only what amino acids are, but also why they are important. It helps them connect molecular structure with biological function and practical applications. A bilingual learning context further enriches this process by developing students' scientific vocabulary and academic communication skills. Through bilingual terminology, students learn to express chemical ideas in both their native language and English. This is especially important in modern science education, where access to international scientific information requires language competence.

The integration of problem-based learning and bilingual instruction in teaching amino acids can improve students' conceptual understanding, motivation, collaboration, and scientific literacy. This approach may serve as a useful methodological model for modern chemistry education.

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PHILOLOGICAL SCIENCES

SPACE AND TIME IN THE WORKS OF I. A. BUNIN "MANY WATERS" AND "CURSED DAYS"

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ПРОСТРАНСТВО И ВРЕМЯ В ПРОИЗВЕДЕНИЯХ И.А.БУНИНА «ВОДЫ МНОГИЕ» И «ОКАЯННЫЕ ДНИ»

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Abstract

The article examines the peculiarities of the representation of the lexical-semantic field of "time" in Ivan Bunin's work *Cursed Days*. The study analyzes linguistic means of expressing temporality, the functioning of time-related lexemes, their syntagmatic connections, and their artistic and stylistic role in the text. Special attention is paid to the symbolism of time, the opposition between the past and the present, as well as the relationship between temporal images and the emotional-evaluative system of the work. The research demonstrates that the category of time in Bunin's творчество functions not only as a means of organizing narration, but also as an important instrument for conveying the author's worldview and philosophical interpretation of historical reality.

Аннотация

В статье рассматриваются особенности репрезентации лексико-семантического поля «время» в произведении И.А. Бунина «Окаянные дни». Анализируются языковые средства выражения темпоральности, функционирование лексем со значением времени, их синтагматические связи и художественно-стилистическая роль в тексте. Особое внимание уделяется символике времени, противопоставлению прошлого и настоящего, а также взаимосвязи темпоральных образов с эмоционально-оценочной системой произведения. Исследование показывает, что категория времени в творчестве И.А. Бунина выступает не только средством организации повествования, но и важным инструментом передачи авторского мировосприятия и философского осмысления исторической действительности.

Keywords: Ivan Bunin, category of time, lexical-semantic field, Cursed Days, literary text.

Ключевые слова: И.А. Бунин, категория времени, лексико-семантическое поле, «Окаянные дни», художественный текст.

В дневниковых произведениях И.А. Бунина "Воды многие" и "Окаянные дни" достаточно широко представлены языковые единицы, характеризующие Пространство и Время.

Пространственно-временные категории образуют дихотомическую связь между этими произведениями: если в названии произведения «Воды многие» шире представлены пространственные отношения, то в заглавии «Окаянные дни» очевидны более тесные взаимодействия текстовых категорий времени и пространства. Точечная цитата воды многие напрямую относится к категориям свобода и простор, организуя видимое бесконечное пространство. В то же время, являясь метафорическим оборотом, название вбирает в себя пространственный смысл, олицетворяя всю Землю (планету), а не только водное пространство.

Метафора окаянные дни заключает в себе временной интервал. Ключевое слово дни, которое относится к ЛСП Время, является частью культурного тезауруса И. А. Бунина и имеет особый смысл в произведении. Однако в дневнике «Окаянные дни» наблюдается тесная взаимосвязь времени с пространством, которая имеет территориальную обусловленность: речь идет о событиях в России (в первой главе действия происходят в Москве, во второй – в Одессе).

В дневнике «Воды многие» важную роль играет путь, маршрут, по которому проходит путешествие. Путь героя-повествователя начинается от Порт-Саида, из которого он стремится уплыть к "обетованной земле", в "рай" – на о. Цейлон и Коломбо. А завершается, когда до пункта назначения остается одна ночь. Следует обратить внимание на то, что в данной ситуации расстояние, оставшееся до пункта назначения, герой измеряет временным интервалом, то есть время и пространство условно оказываются на одной линейной оси. Такое восприятие времени (сквозь призму пространства) свойственно фольклорным произведениям (Ср: в русских сказках точное расстояние до объектов никогда не указывается, указывается лишь, как герой

скачет к своей цели три дня и три ночи). Необходимо отметить, что повествование неслучайно обрывается на том месте, когда герой находится "в преддверии рая" и до цели остается совсем немного. Во-первых, благодаря этому остается впечатление недосказанности, которое приводит к множеству интерпретаций текста и к его домысливанию. А вовторых, это может быть связано с изменениями в мировоззрении писателя, который в последние годы поменял свое отношение к России. Известно, что И. А. Бунин сократил это произведение, опустив описание обратной дороги в Одессу. Писатель негативно относился к большим городам. В письме брату Юлию от 3 апреля 1895 г. он писал: "Будь они прокляты эти города!" [1, с.50]. Город, по его мнению – это "Хлябь, хаос – царство сатаны/Губящего слепой стихией" [1, с. 419], поэтому рассказ о путешествии заканчивается в океане – в преддверии рая, символом которого выступает созвездие Южного Креста. Рай ассоциируется в произведении с островом, так как это всегда место, огражденное или окруженное морем или открытое только небесам, что в данном случае противоречит христианской традиции, в которой райской землей считается Новый Иерусалим. Традиционно рай символизирует изначальное совершенство, космический центр, гармонию между Богом, человеком и всеми живыми существами, вечной жизнью. Остров олицетворяет собой замкнутое пространство.

Герой-повествователь неслучайно указывает, прежде всего, на форму и размеры: прошли остров Джебель-Таир <…> совершенно четкий, голый и со всех сторон точно топором обрублен; слева шли мелкие острова.

Путешествие к острову происходит на пароходе, который также создает ощущение замкнутого пространства и символизирует технический прогресс. Тема технического развития звучит и в «Окаянных днях», где такие транспортные и военные средства как грузовики и броневики являются символом революционной эпохи, нового времени и олицетворяют собой замкнутое пространство, несвободу.

В "Окаянных днях" несвободу нередко олицетворяют предметы окружающей действительности, например, важным символом этого является веревка. Данная лексема используется писателем пять раз и воплощает значения, характерные для русской языковой картины мира (ср. фразеологизм: вить веревки – заставлять кого- либо поступать по своему желанию, подчинять всецело своей воле [7, с. 69]), где веревка является аллегорическим символом социального угнетения, инструментом мученичества, знаком неволи, зависимости, подчиненности, несвободы, смерти: матрос и красноармеец, казак и мужик крутят веревками отвратительную зеленую жабу с выпученными буркалами - буржуя; подпись: "Ты давил нас толстой пузой". Здесь, в отличие от произведения «Воды многие», ощущение несвободы связано с внутренними душевными переживаниями дневниciста по поводу происходящего.

Образом открытого пространства в "Водах многих" становится палуба корабля – идеальное место для созерцания неба. Именно на палубе под открытым небом возникает ощущение счастья. Позитивным эмоциям способствует атмосфера, позволяющая созерцать окружающий мир. Налицо перекличка с идеями Л. Н. Толстого, который утверждал, что именно "жизнь под открытым небом, при свете солнца, при свежем воздухе, общение с землей, растениями, животными <…> одно из первых и всеми признаваемых условий счастья" [5]. Все это позволяет говорить о том, что базовыми в языковой картине мира И. А. Бунина являются такие понятия, как свобода, счастье, простор.

Важными пространственными лексемами в произведении «Воды многие» являются иллюминатор/окно и дверь, которые в русской языковой картине мира воспринимаются как пограничные символы, имеющие мистический смысл. Они олицетворяют связь между пространствами и мирами. Нельзя не отметить, что слово окно, которое обычно связывают с образом дома, употребляется в контексте произведения чаще, чем слово иллюминатор. Писатель неслучайно отдает предпочтение лексеме окно, ведь на корабле герой повествователь чувствует себя как дома: обед имел совсем домашний характер. По домашнему приготовлялось и кофе, – не в поварской, а в столовой, собственноручно, то есть корабль в «Водах многих» соотносится с образом дома, который является важным для русской лингвокультуры. Семантика лексемы дом в контексте творчества писателя определяется во многом его судьбой, жизненными обстоятельствами. Известно, что, покинув отчий дом, И.А. Бунин не имел собственного крова и провел большую часть жизни в гостиницах и съемных квартирах, поэтому для него дом – это, прежде всего, родина, с которой он чувствует связь. Однако в свете исторических перемен это теплое отношение к родине изменилось, так как писатель чувствовал свою ненужность родной стране.

С лингвокультурологической точки зрения наибольший интерес представляет семантика слова дом в дневнике «Окаянные дни», где оно встречается шестьдесят пять раз в значении "здание, жилое помещение, квартира". Однако дом здесь олицетворяет не только определенное замкнутое пространство, но и всю Россию. Такое понимание дома свойственно многим русским писателям, в частности В. В. Набокову, который так же, как и И.А. Бунин, лишился Родины.

Исходя из вышесказанного, можно заключить, что лексема Россия является одной из ключевых единиц, так как с ее помощью И. А. Бунин дает оценку обществу, русскому народу, собственной жизни и деятельности, определяя тем самым место каждого человека не только в геополитическом, но и в социокультурном пространстве.

Важно отметить, что у И. А. Бунина образ России представлен по-разному (как отдельное великое государство, как страна с определенными конкретными границами, как территория, на которой проживает русский народ). С одной стороны, это бескрайняя страна, а, с другой, государство с четко определенными территориями. Кроме того, Россия

для него делится на "до" и "теперь", то есть писатель оценивает ее в пространственно-временных оппозициях (прошлое-настоящее, свое-чужое, русское-азиатское или европейское).

Писатель является консерватором и ценит старые традиции, прежний уклад жизни. Поэтому неслучайно наряду с лексемой Россия, которая употребляется в произведении «Окаянные дни» более тридцати раз, используется устаревшая форма – Русь. По его мнению, страна пошла по ложному пути, на котором неизбежна гибель традиций и культуры, поэтому Россия ассоциируется с концом, смертью, преступлением, могилой.

Отметим, что в произведении «Воды многие» Россия не соотносится с образом дома, который, как мы указывали выше, является ключевым в тексте И. А. Бунина. Лексема дом употребляется всего трижды и ассоциируется с родовым, человеческим гнездом. Такое метафорическое сравнение является вполне традиционным для русской литературы, особенно для писателей дворянского сословия (Ср. «Дворянское гнездо» И. С. Тургенева).

Однако у И. А. Бунина оно приобретает негативный оттенок.

Пространство в дневнике «Воды многие» предстает не только как открытое или замкнутое, но и как горизонтальное (водная поверхность и суша) и вертикальное (ярусы корабля). Эти параметры нужны писателю, чтобы осуществлять связь человека с небесами и Богом. Горизонтальное пространство в дневнике символизируют горизонт и берег. Горизонт является не только пространственной характеристикой, но еще и ориентиром движения, которое направлено вперед. Символом вертикального пространства является и гора Синай. Однако вертикальное пространство образуют не только лексемы, обозначающие надводные реалии окружающего мира, но и другие понятия, в том числе абстрактные, например, глубина.

Как уже было отмечено, в произведении «Воды многие» с категорией пространства тесно связано время, что обусловлено жанровой спецификой произведения, имеющего черты путевого очерка, где сюжетное движение определяется мотивом времени, идущего сквозь пространство. Неслучайно И. А. Бунин зачастую указывает точную дату, время суток (день или ночь) и место, где происходит описываемое событие, например: 13 февраля, Суэцкий канал.

В «Водах многих» обращают на себя внимание пространственные наречия и предлоги, которые участвуют в описании временных границ в произведении. Кроме наречий, семантическое поле времени образуют имена существительные и прилагательные. Заметим, что при употреблении временных характеристик И. А. Бунин нередко прибегает к употреблению тавтологических конструкций, которые являются устойчивыми оборотами и распространенными "дейктичными формулами" движения и выражения реального времени: целые тысячелетия, из века в век, из часа в час; из тысячелетий в тысячелетия; ибо во веки веков будет свято чувство рожденного к родившим его, что свидетельствует о "синтетичности восприятия времени и синкретизме сознания как такового" [4, с. 124].

В «Окаянных днях» время – важнейшая категория. Основной временной интервал здесь – день, который способствует соблюдению хронологии излагаемых событий. Н. В. Уфимцева считает, что день является наиболее актуальным временным отрезком для современного русского языкового сознания [6]. А исследователь категории времени Л. Н. Михеева замечает: «день как слепок жизни <…> является выразителем «некоего "вещного" плана жизни» [4, с. 192]. И. А. Бунин хорошо это понимал и мыслил жизнь, существование как "смену дней и ночей, дел и отдыха, встреч и бесед, удовольствий и неприятностей, иногда называемых событиями" [4, с. 405]. Кроме этого, «во множественном числе слово "день" приобретает в устойчивых словосочетаниях дополнительные значения» [4, с. 193]. В названии анализируемого произведения в сочетании с прилагательным окаянный слово дни приобретает не только оттенок длительности, но и эмоционально-оценочный, аксиологический характер. В «Окаянных днях» слово дни соотносится с определенными словами.

Так, например, чаще всего вступает в синтагматические отношения с прилагательными пустые, последние, долгие в отличие от произведения «Воды многие», где дни характеризуются писателем в основном как легкие, веселые, прекрасные, дни труда, лишь иногда как облачные, мутные. Лексема день встречается и в составе фразеологизма: этому народу сто лет долбили, что единственное его спасение – это отнять у тысячи помещиков те десятины, которые и так не по дням, а по часам таяли в их руках. ФЕ не по дням, а по часам является устойчивым выражением, в основе которого лежит сказочная формула, обозначающая быстро протекающий процесс. В русских сказках данная фразеологическая единица гиперболизирована и обычно описывает положительный процесс: то, как быстро растет и развивается ребенок (ср. у А.С. Пушкина в «Сказке о царе Салтане»: "И растет ребенок там / Не по дням, а по часам…"). У И. А. Бунина она приобретает иной характер, передавая негативное настроение, оценку, мнение по поводу происходящего.

Важно отметить, что в произведении «Окаянные дни» наиболее значима синтагматическая связь слово дни с прилагательным окаянный. Оценочный эпитет окаянный, проклятый является языковой особенностью фольклорной фразеологии (ср. в былинах змеище проклятое). Поэтому можно говорить о межжанровых связях «Окаянных дней» с русскими былинами, в которых прилагательное окаянный ассоциируется со злыми силами. Кроме этого в нем присутствуют черты, характерные для жанра летописи. Здесь так же, как в летописи, повествование ведется посредством коротких записей, связанных с настоящим или недавним прошлым. Это требует использования глагольных форм настоящего и прошедшего времени, преобладают же глаголы прошедшего времени. Прошлое у

И. А. Бунина действительно выходит на первый план (что также подтверждается преимущественным употреблением глаголов в прошедшем времени). Но есть и другой способ обозначения прошлого, заключающийся в использовании словосочетаний, где главным словом являются существительные время, дни, а в качестве зависимых выступает либо указательное местоимение тот, либо притяжательное местоимение наш. Прошлое характеризуется писателем как те дни; наше время; время наших отцов и дедов и т.п. Интересно и то, что в контексте произведения прошлое противопоставлено не будущему, а настоящему. В контексте сказанного наиболее значимым выступает метафорическое противопоставление старость/старый – молодость/молодой, где указанные лексемы воспринимаются не только как категории возраста, но и как единицы, грамматически выражающие отношение к прошлому или настоящему. Обращает на себя внимание неоднократно повторяющаяся опорная лингвокультурная универсалия "светлое будущее", которая базируется на универсалии "разрушения" сегодня [8, с. 137]. Необходимо отметить, что у И.А. Бунина свое философское восприятие времени, в котором именно прошлое первостепенно.

Время в «Окаянных днях» широко представлено лексемами, называющими времена года и месяцы. Наиболее частотная лексема весна, она является символом новой жизни, возрождения, надежды. Важно подчеркнуть, что ассоциация времени с жизнью, бытием является ключевой не только в анализируемых произведениях, но и во всем творчестве писателя, так как жизнь, в свою очередь, понималась им как "непрестанное, ни на единый миг нас не оставляющее течение несвязных чувств и мыслей, беспорядочных воспоминаний о прошлом и смутных гаданий о будущем" [2, с. 405].

Таким образом, ЛСП Время вербализовано различными лексемами, такими как: наименование времен года, месяцев, а также частей суток; совокупность дней, часов; определенный момент или период времени; наименования, относящиеся к прошлому, настоящему или будущему; категория возраста и срока, а также длительность бытия. При этом все лексические единицы, формирующие ЛСП Время, выполняют определенные функции: с одной стороны, они создают темпоральный план произведению, а с другой, являются художественным средством выражения эмоций, состояния и оценок.

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PHILOSOPHICAL SCIENCES

FALSIFICATION, CRITICAL RATIONALISM, AND THE GROWTH OF KNOWLEDGE: POPPER'S FRAMEWORK REVISITED THROUGH COMPARATIVE AND APPLIED ANALYSIS

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Abstract

This article examines Karl Popper's philosophy of science with focus on the epistemological foundations of critical rationalism, his three basic requirements for the growth of scientific knowledge, and the principle of falsification. Through comparative analysis of Popper, Kuhn, and Lakatos, and an applied case study assessing the falsifiability of selected scientific and linguistic theories, the article argues that Popper's normative account retains foundational importance for evaluating scientific progress. The findings are discussed in relation to applied linguistics and foreign language teacher education, where Popperian critical scrutiny offers a model of evidence-sensitive reflective practice.

Keywords: falsification, critical rationalism, growth of knowledge, demarcation problem, philosophy of science, Karl Popper, Thomas Kuhn, Imre Lakatos, applied linguistics.

1.Introduction

The problem of the growth of knowledge has been central to philosophy since antiquity. Classical thinkers such as Socrates and Aristotle raised fundamental questions about the nature of truth, logical reasoning, and the justification of belief. Aristotle's development of formal logic established the first systematic framework for evaluating arguments, thereby laying the groundwork for later conceptions of scientific rationality [1].

During the early modern period, the issue evolved into a methodological problem concerning the foundations of science. Empiricists emphasized observation and induction, while rationalists stressed deductive reasoning. The formulation of the problem of induction by David Hume demonstrated the logical difficulty of justifying universal scientific laws based solely on empirical observations [2, 3].

In this intellectual context, Karl Popper proposed a revolutionary solution. Rejecting inductivism and verificationism, Popper argued that scientific knowledge does not grow through confirmation but through bold hypotheses subjected to rigorous attempts at refutation [4]. In The Logic of Scientific Discovery (2002), he introduced the principle of falsification as the criterion distinguishing scientific theories from metaphysical or pseudoscientific claims. According to Popper, a theory is scientific only if it can, in principle, be falsified by empirical evidence.

Popper's ideas stimulated extensive debate. Thomas S. Kuhn (2012) questioned whether scientific development follows continuous critical testing, proposing instead that science evolves through paradigm shifts involving historical and sociological dimensions [5]. Imre Lakatos (2004) attempted to reconcile falsificationism with historical practice by introducing the concept of scientific research programmes [6]. Other scholars, including Chalmers (2007), Rosenberg (2000), and Ladyman (2002), critically assessed the strengths and limitations of falsification as a methodological principle [7].

Despite these critiques, Popper's theory remains foundational in contemporary discussions about scientific rationality. His emphasis on logical consistency, empirical testability, and openness to criticism continues to influence debates concerning the demarcation problem, theory change, and the structure of scientific explanation [10].

2.Methodology

This study employed a qualitative comparative-analytical methodology grounded in the traditions of philosophical and epistemological inquiry. The research combined theoretical analysis, comparative analysis, and an applied case-study approach in order to evaluate Karl Popper's philosophy of science and its contemporary relevance [14].

The first stage of the research involved a systematic review of primary and secondary philosophical literature related to critical rationalism, falsificationism, and the growth of scientific knowledge. Primary sources included the major works of Karl Popper, particularly The Logic of Scientific Discovery, alongside theoretical contributions by Thomas S. Kuhn and Imre Lakatos. Secondary academic sources in philosophy of science were used to contextualize and critically interpret these frameworks [17].

The second stage applied a comparative analytical method to identify similarities and differences between the philosophical models proposed by Popper, Kuhn, and Lakatos. The comparison focused on five analytical categories: the mechanism of scientific progress, the

role of falsification, the concept of rationality, the criterion of demarcation, and the treatment of scientific anomalies. This approach enabled the study to evaluate the strengths and limitations of each framework within twentieth-century philosophy of science [9].

The third stage employed a qualitative case-study analysis of selected theories from physics, biology, psychology, linguistics, and pseudoscience. Theories were selected according to their historical significance and relevance to the problem of falsifiability. Each theory was examined using Popper's criterion of empirical refutability in order to determine whether it satisfied the requirements of scientific status. The analysis focused particularly on the extent to which each theory generated testable predictions, permitted potential refutation, and demonstrated empirical openness.

To ensure methodological reliability, the study relied on peer-reviewed academic literature and canonical philosophical texts. The analysis followed principles of interpretive consistency and conceptual triangulation by integrating historical, logical, and applied perspectives. Although the study is theoretical rather than empirical, the inclusion of comparative and applied analysis strengthened the explanatory depth and practical relevance of the research [8].

3.Literature reiew

The philosophy of science in the twentieth century was significantly shaped by the works of Karl Popper, Thomas Kuhn, and Imre Lakatos. Among these thinkers, Popper developed one of the most influential methodological approaches through his theory of critical rationalism and the principle of falsification. In *The Logic of Scientific Discovery*, Popper rejected verificationism and argued that scientific theories cannot be conclusively proven true but can be critically tested and potentially falsified [4].

Popper's ideas emerged partly as a response to the problem of induction formulated by David Hume. According to Popper, scientific progress does not occur through the accumulation of confirming observations but through conjectures and refutations. Scientific theories advance only when they survive severe empirical tests [11].

Thomas Kuhn criticized Popper's model by emphasizing the historical and sociological dimensions of science. In *The Structure of Scientific Revolutions*, Kuhn argued that scientists normally work within dominant paradigms and often preserve existing theories despite anomalies [5]. Scientific revolutions occur only when crises lead to paradigm shifts that transform the conceptual framework of an entire discipline.

Imre Lakatos attempted to reconcile Popper's falsificationism with Kuhn's historical perspective. His methodology of scientific research programmes proposed that scientists do not abandon theories immediately after falsification but protect them through auxiliary hypotheses. According to Lakatos, a research programme remains scientific if it continues generating novel and empirically successful predictions [13].

Contemporary scholars such as Chalmers, Rosenberg, and Ladyman further examined the strengths and limitations of falsificationism. Discussions surrounding the Duhem–Quine thesis demonstrated that empirical testing is often more complex than Popper initially suggested because theories are tested together with multiple auxiliary assumptions. Nevertheless, Popper's emphasis on empirical testability, rational criticism, and intellectual openness remains foundational within modern philosophy of science.

Recent interdisciplinary studies have also highlighted the relevance of Popperian ideas in education and applied linguistics, particularly in evidence-based pedagogical research and reflective teaching practice. Critical evaluation of theories and openness to revision continue to represent essential principles of academic inquiry across disciplines.

4. Epistemological foundations of Popper's critical rationalism

Karl Raimund Popper (1902-1994) was one of the most influential philosophers of science of the twentieth century. Born in Vienna, he developed his ideas in an intellectual environment shaped by logical positivism and the Vienna Circle. While Popper shared the empiricist commitment to scientific rigour, he fundamentally disagreed with the verificationist criterion of meaning proposed by the positivists.

Popper's epistemology begins with a rejection of the classical theory of knowledge based on justification and certainty. He argued that this search for certainty was misguided and philosophically unproductive. Instead, he proposed that knowledge is inherently fallible: we can never be certain that our theories are true, but we can test them rigorously and discard those that fail [4].

A central motivation for Popper's epistemology was his response to the problem of induction. Hume demonstrated that no finite number of observations can logically justify a universal statement: a single black swan refutes the claim that all swans are white. Popper accepted Hume's critique but drew a different conclusion - rather than confirming theories through observation, science should proceed by attempting to falsify them [7].

This insight gave birth to Popper's theory of critical rationalism. For Popper, rationality does not consist in accumulating confirmations but in subjecting ideas to relentless critical scrutiny. Theories that survive genuine attempts at refutation are said to be 'corroborated,' though never conclusively verified. Those that fail must be rejected or revised.

The concept of objective knowledge is central to Popper's epistemology. He distinguished between subjective knowledge (beliefs, psychological states) and objective knowledge (the content of theories, arguments, and problems existing independently of any knowing subject). Objective knowledge inhabits what Popper called 'World 3' - the world of logical contents of books, scientific theories, and other artefacts of the human mind.

4.1.Three basic requirements for the growth of knowledge

Karl Popper's theory of the growth of scientific knowledge is not merely a negative thesis about falsification. He also developed a constructive account of what conditions a new theory must satisfy in order to represent genuine scientific progress. In The Logic of

Scientific Discovery and subsequent works, Popper articulated three basic requirements that a new theory must meet in order to count as an improvement over its predecessor.

Requirement I: A Simple, New, and Fruitful Idea:

The first requirement is that a new theory must be guided by a simple, unified, and scientifically fruitful idea. Popper argued that theories should not be arbitrary collections of ad hoc hypotheses designed to save a predecessor from refutation. Instead, a good theory should propose a genuinely new explanatory principle that unifies previously disconnected phenomena.

Simplicity, in Popper's sense, is not merely aesthetic. A simpler theory makes more precise and universal claims, and is therefore more easily falsifiable. Newton's law of universal gravitation, for example, was simpler and more powerful than the collection of empirical regularities it replaced, precisely because it explained and predicted a vast range of phenomena with a small number of principles.

Fruitfulness refers to the capacity of the new idea to open up new lines of empirical investigation and to generate new, testable predictions. A theory that merely redescribes known facts without suggesting new experiments is scientifically sterile. Genuine progress involves theories that point beyond the known, inviting further critical testing.

Requirement II: Independent Testability:

The second requirement is that the new theory must be independently testable - it should make predictions that can be checked independently of the specific observations that motivated the theory. A theory that can only be tested against the very evidence that led to its formulation provides much weaker epistemic support than one that generates novel, unexpected predictions.

Popper called the independently testable and surprising predictions of a theory 'excess content.' A new theory has more empirical content than its predecessor if it forbids more possible states of the world. Einstein's General Theory of Relativity not only explained the precession of Mercury's perihelion, but also predicted the bending of light by gravity - a phenomenon entirely outside the domain of the original problem. This excess content made Einstein's theory a prime example of genuine scientific progress [8].

Independent testability also serves as a guard against what Popper called 'conventionalist stratagems' - the practice of modifying theories in response to refuting evidence by adding auxiliary hypotheses that protect the core claims from falsification [4].

Requirement III: Passing New and Severe Tests:

The third requirement is the most stringent: the new theory must actually pass some new and severe empirical tests. It is not enough to merely propose a bold, independently testable theory. The theory must survive serious attempts at refutation. A theory that has not yet been subjected to genuine tests remains a conjecture, however promising it may appear.

Popper introduced the concept of corroboration to describe the degree to which a theory has withstood critical testing. A highly corroborated theory is one that has survived many severe tests, especially tests that it was genuinely at risk of failing. Corroboration is not the same as probability or confirmation. It is a backward-looking measure of a theory's past performance, not a forward-looking indicator of its truth [6].

The severity of a test is crucial. Eddington's 1919 observation of the deflection of starlight during a solar eclipse constituted a severe test of General Relativity because the predicted deflection could easily have been absent or different. The fact that observation matched prediction to high precision significantly corroborated the theory [10].

4.2.The principle of falsification and its philosophical significance

The Logic of Falsification:

Popper's falsification principle is grounded in the logical asymmetry between verification and falsification. While no finite number of confirming instances can logically prove a universal statement true, a single counterexample is logically sufficient to prove it false. The argument takes the form of modus tollens: if a theory T implies observation O, and O is observed to be false (not-O), then T must be false.

This logical asymmetry has profound methodological implications. Popper argued that scientists should actively seek to refute their theories rather than confirm them. The practice of seeking confirmation - 'verificationism' - leads scientists to overlook disconfirming evidence. By contrast, a scientist committed to falsificationism designs experiments that give theories a genuine chance of failing [7].

Demarcation: Science vs. Non-Science:

One of Popper's primary motivations for developing the falsification criterion was to solve the problem of demarcation - distinguishing genuine science from pseudoscience, metaphysics, and ideology. He was particularly troubled by the contrast between the testability of Einstein's relativity and the apparent immunity from refutation of Freudian psychoanalysis and Adlerian individual psychology.[4]

Popper observed that practitioners of these psychological theories were able to find confirmation everywhere. Every human behaviour, no matter how seemingly contradictory, could be explained in terms of unconscious desires or feelings of inferiority. This unlimited explanatory power was, for Popper, a sign of scientific weakness rather than strength.[4]

By contrast, Einstein's general relativity made specific, risky predictions - such as the bending of light near massive objects - that could have been decisively refuted by observation. It was precisely this willingness to be tested that made it scientific. Popper's demarcation criterion thus redirected attention from 'Can this theory be confirmed?' to 'Can this theory be refuted, and how?'

Critical Reception:

Thomas Kuhn argued that scientists do not in fact behave as Popper described. During periods of 'normal science,' anomalies are routinely ignored or explained away rather than leading to the immediate rejection of the dominant paradigm. Falsification, Kuhn suggested, is a philosophical ideal that does not adequately capture the social and historical reality of scientific practice [5].

Imre Lakatos developed a sophisticated response with his methodology of scientific research programmes. He accepted that scientists often protect the 'hard core' of their theories using a 'protective belt' of auxiliary hypotheses, arguing that this was not necessarily irrational, provided the overall research programme remained progressive - continuing to generate novel, confirmed predictions.

Alan Chalmers and other critics pointed out that falsification is complicated by the Duhem-Quine thesis: when an experiment yields a result that contradicts a theory, it is never clear whether the theory itself or one of the many auxiliary assumptions is to blame [7].

Despite these challenges, the falsification principle retains its philosophical importance. Its relevance is particularly acute today, in an era of misinformation and pseudoscience, where the capacity to distinguish empirically testable claims from non-testable ones is of pressing practical importance.

5. Results. Comparative analysis: Popper, Khun and Lakatos

This section presents a systematic comparison of the three most influential frameworks in twentieth-century philosophy of science. While all three thinkers addressed the question of how scientific knowledge grows, they arrived at substantially different answers. Table 1 provides a structured overview of key differences and convergences [5].

Table 1

Comparative overview of Popper, Kuhn, and Lakatos

Criterion	Karl Popper	Thomas Kuhn	Imre Lakatos
Core idea	Knowledge grows through falsification and critical testing	Science advances via paradigm shifts and revolutions	Science progresses through competing research programmes
Unit of analysis	Individual theories	Paradigms (worldviews)	Research programmes (series of theories)
Role of falsification	Central: one counterexample can refute a theory	Marginal: anomalies tolerated within paradigms	Modified: a programme is abandoned only if a better one exists
Demarcation	Falsifiability distinguishes science from non-science	Normal vs. revolutionary science - no sharp criterion	Progressive vs. degenerative research programmes
Rationality	Logic-driven; open to criticism	Partly sociological; shaped by scientific community	Rational but historically sensitive
Weakness	Ignores role of scientific communities and history	Relativistic; hard to compare paradigms	Hard to determine when a programme is truly degenerative

As Table 1 illustrates, Popper's framework is the most logically rigorous and normatively demanding. Kuhn's account of normal science correctly describes the way in which scientists operate within established frameworks for long periods. Lakatos's notion of research programmes captures the way in which scientists are often rational to persist with a research tradition even in the face of apparent anomalies, provided the programme continues to generate new knowledge [6].

Case study – applying the falsification criterion to scientific and non-scientific theories

The following case study applies Popper's falsification criterion to six theories drawn from the natural sciences, psychology, and linguistics. The aim is to demonstrate how the criterion operates in practice and to illustrate why some theories qualify as scientific while others do not [8].

Table 2

Falsifiability analysis of selected theories

Theory	Key Claim	Falsifiable?	Verdict	Domain
Einstein's General Relativity	Gravity bends light - tested by the 1919 solar eclipse	Yes	Scientific ✓	Physics
Freud's Psychoanalysis	All behavior driven by unconscious desires; objections reinterpreted as resistance	No	Non-scientific ✗	Psychology
Krashen's Input Hypothesis	Language acquired only through comprehensible input (i+1)	Partially	Disputed ⚠	Linguistics
Chomsky's Universal Grammar	All humans have an innate language faculty; specific claims hard to test	Partially	Disputed ⚠	Linguistics
Darwin's Natural Selection	Species evolve through variation and selection - tested via fossil record and genetics	Yes	Scientific ✓	Biology
Astrology	Planetary positions determine personality - vague enough to explain anything	No	Non-scientific ✗	Pseudoscience

The case studies reveal several important patterns. First, the most widely accepted and productive scientific theories - such as General Relativity and natural selection - make specific, risky, and independently testable predictions. Their scientific status is not merely the result of institutional recognition but of their genuine openness to empirical refutation.

Second, the cases of Freudian psychoanalysis and astrology illustrate Popper's central concern. As he wrote, 'a theory which is not refutable by any conceivable event is non-scientific. Irrefutability is not a virtue of a theory but a vice.'

Third, the cases of Krashen's Input Hypothesis and Chomsky's Universal Grammar occupy a more ambiguous middle ground. These theories contain some falsifiable components but also rely on theoretical constructs that are difficult to operationalise and test independently. This ambiguity reflects a genuine challenge in the human sciences, where the complexity of the subject matter makes strict falsifiability harder to achieve [7].

For foreign language teachers, this analysis has direct relevance. The theoretical frameworks underpinning language teaching methodology - communicative language teaching, task-based instruction, content and language integrated learning - all rest on empirical claims about language acquisition. Applying Popperian scrutiny to these frameworks encourages teachers to adopt a critically reflective stance: to ask not only 'Does this method work?' but 'Under what conditions could it fail, and how would we know if it did?' This epistemic humility is itself a form of professional development aligned with the spirit of Popper's critical rationalism.

6. Discussion

The findings of this study support the continuing relevance of Popper's philosophy in contemporary scientific and educational discourse. Despite extensive criticism from post-positivist and sociological approaches to science, falsificationism remains a powerful methodological ideal because it promotes intellectual openness, logical consistency, and resistance to dogmatism.

The comparative analysis demonstrated that Kuhn and Lakatos successfully identified limitations in Popper's original formulation. Kuhn's emphasis on paradigms and scientific communities explains why scientists often preserve dominant theories despite anomalies. Similarly, Lakatos's concept of research programmes offers a more historically realistic account of how scientific theories evolve over time. Nevertheless, neither Kuhn nor Lakatos fully rejected the importance of empirical criticism. Instead, their frameworks may be interpreted as modifications rather than complete replacements of Popperian rationalism.

An important implication of the findings concerns the distinction between scientific explanation and ideological or pseudoscientific reasoning. In the contemporary information environment, where misinformation and non-evidence-based claims circulate widely, Popper's falsification criterion retains practical significance as a tool for evaluating the credibility of knowledge claims. The ability to distinguish empirically testable theories from unfalsifiable assertions remains essential for both scientific literacy and critical thinking [17].

The study also highlighted challenges associated with applying falsificationism in the human sciences. Unlike natural sciences, disciplines such as psychology and linguistics often investigate complex and context-dependent phenomena that are difficult to isolate experimentally. As a result, strict falsifiability may not always be achievable in the same form as in physics or biology. However, this limitation does not invalidate Popper's framework; rather, it suggests the need for methodological adaptation when dealing with socially and cognitively complex phenomena.

In the context of foreign language education, the findings reinforce the importance of reflective pedagogy grounded in empirical evaluation. Educational theories and teaching methodologies should not be accepted solely on the basis of popularity or theoretical elegance. Instead, they should remain open to critical assessment, classroom-based evidence, and ongoing revision. Such an approach aligns closely with Popper's principle that knowledge advances through conjecture, criticism, and correction.

Overall, the study confirms that Popper's philosophy continues to provide a foundational framework for understanding scientific inquiry. Although contemporary philosophy of science has moved beyond strict falsificationism, the core principles of critical rationality, testability, and openness to refutation remain central to modern conceptions of scientific knowledge and academic inquiry [18].

7. Conclusion

This article has examined Karl Popper's philosophy of science, focusing on the epistemological foundations of critical rationalism, his three basic requirements for the growth of knowledge, and the principle of falsification.

The three requirements - that a new theory must proceed from a simple and fruitful idea, must be independently testable, and must pass new and severe tests - provide a demanding but constructive standard for evaluating scientific progress. They reflect a deep commitment to intellectual honesty, critical thinking, and openness to refutation.

The comparative analysis of Popper, Kuhn, and Lakatos has shown that while each framework captures important aspects of scientific practice, Popper's normative account retains its foundational importance. His insistence on testability, corroboration, and the rejection of dogmatism continues to serve as a vital corrective to confirmation bias and pseudoscientific reasoning.

The applied case study demonstrated that the falsification criterion is not merely of abstract philosophical interest. It operates as a practical tool for evaluating the scientific status of theories across disciplines, including applied linguistics. For the field of foreign language teaching, Popper's ideas offer a model of reflective, evidence-sensitive professional practice.

In conclusion, Karl Popper's contribution to the philosophy of science remains indispensable. His ideas challenge us to think rigorously, to test boldly, and to embrace the fallibility of our knowledge as a source of intellectual strength rather than weakness.

8. Limitation

This study is theoretical and qualitative in nature and does not include quantitative empirical investigation. The research is primarily based on interpretive analysis of philosophical texts and selected case studies. Consequently, the conclusions may not fully represent all contemporary perspectives within philosophy of science or applied linguistics. In addition, the application of falsificationism to human sciences remains methodologically complex due to the interpretive and context-dependent nature of social phenomena.

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ANTHROPOLOGICAL ISSUES IN ISLAM

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АНТРОПОЛОГИЧЕСКИЕ ВОПРОСЫ В ИСЛАМЕ

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Abstract
The article is devoted to anthropological issues in Islam. Based on the study of Muslim theological literature, the following issues are addressed: the sources of Muslim anthropology; the creation of Adam and Eve; the creation of the souls of humanity; the duties of a person as a caliph; the concepts of «nafs» and «rukh»; the spiritual and physical health of a person; and the types of worship. The article concludes that the meaning of human life is defined as the knowledge of the Almighty and the worship of Him, in order to achieve paradise bliss and salvation after earthly life.

Аннотация
Статья посвящена антропологическим вопросам в исламе. На основе изучения мусульманской богословской литературы раскрываются следующие вопросы: источники мусульманской антропологии; сотворение Адама и Хавы; творение душ человечества; обязанности человека как халифа; понятия «нафс» и «рух»; духовное и физическое здоровье человека; виды поклонения. Делается вывод: смысл жизни человека определяется как познание Всевышнего и поклонение ему для того, чтобы достичь райского блаженства и спасения после земной жизни.

Keywords: Allah, Islam, Muhammad, nafs, worship, ruh, caliph, man.
Ключевые слова: Аллах, ислам, Мухаммед, нафс, поклонение, рух, халиф, человек.

В условиях экспансии мусульманской культуры в целях адекватного восприятия исламской традиции актуальными представляются антропологические вопросы в исламе. Мусульманское учение о человеке включает ряд вопросов, связанных с природой человека, его статусом, смыслом жизни, отношениями с Аллахом и др.

В исламе антропологические представления основываются на Коране и Сунне. Коран, согласно исламскому вероучению, есть непосредственное Откровение Аллаха, его пассивный передатчик – пророк Мухаммед. Коран – религиозно-законодательная книга, которая указывает, как жить человеку от рождения до смерти. Сунна для мусульман – Священное предание, в котором описываются действия пророка Мухаммеда в различных обстоятельствах. Пророк выступает нравственным идеалом для приверженцев ислама.

В соответствии с учением ислама человек – достойнейшее творение Аллаха. Специфичным является отсутствие идеи о сотворении человека по образу и подобию Бога. Для ислама бесспорным является утверждение о том, что человек не может быть подобен Аллаху. Мусульмане знают атрибуты (сифаты) и 99 имен Всевышнего, но они по своим характеристикам не схожи с подобными чертами человека [3].

В Коране процесс творения человечества описывается в виде двух периодов. На первом был создан Адам из глины и из его ребра жена Хава. На втором – разрастание человечества через естественные роды и заселение Земли.

Мусульмане считают, что Адама и Хава прожили в раю 1000 лет, в котором они могли наслаждаться всяческими благами, кроме плодов с одного дерева. Шайтан склонил прародителей человечества к греху, и они ослушались Всевышнего. Несмотря на то, что Аллах после покаяния Адама и Хавы простил их, они вынуждены были покинуть Рай, чтобы пройти испытания и вновь вернуться к Господу.

В Коране грех прародителей не мыслится как первородный, который отразился на потомках. В Коране сказано: «О, сыны Адама! Не позволяйте дьяволу совратить вас, подобно тому, как он вывел из Рая ваших родителей. Он сорвал с них одежды, чтобы показать им их срамные места. Воистину, он и его сородичи видят вас оттуда, где вы их не ви-

дите. Воистину, Мы сделали дьяволов покровителями и помощниками тех, которые не веруют» (Коран, 7:27). То есть каждый человек, как и прародители, стоит перед выбором соблюдения законов или их отвержения.

Всевышний сотворил человека идеальным, одарив его красотой внешнего облика и бесчисленными способностями:

- «Мы сотворили человека в прекраснейшем облике» (Коран, 95:4);

- «Мы [говорит Господь миров] чествуем потомков [прародителя человечества] Адама. <…> Перед многим другим из числа сотворенного Нами люди имеют немалое количество преимуществ» (Коран, 17:70).

Любой человек – исключительное создание Бога. В Коране сказано: «Он тот, Кто всему придал форму, дал [индивидуальное] телосложение [отвечающее необходимым для каждого творения потребностям и особенностям], а затем наставил на верный путь [предоставил возможность применять это, гармонично сосуществовать со всем окружающим и просто жить]» (Коран, 20:50).

В Коране говорится о цели, ради которой Господь создал человека: «Я сотворил джиннов и людей только для того, чтобы они поклонялись Мне» (Коран, 51:56). В хадисе-кудси говорится: «Я был сокрытым сокровищем, о котором никто не знал, и Я захотел, чтобы Меня узнали» [1].

В связи с этим в исламе смысл жизни человека определяется как познание Всевышнего и поклонение Ему [8], для того, чтобы достичь райского блаженства и спасения после земной жизни. Мусульманин верит, что законы Всевышнего нужно исполнять с добрыми намерениями, так как в Судный день каждому человеку придется отвечать за свои поступки.

Аллах, заселив Землю, решил поставить на ней наместника (халифа), но никто, кроме человека не взял на себя эту ответственность: «И сказал твой Господь ангелам: Я поставлю на земле наместника» (Коран, 2:30); «Это Он сделал вас наследниками земли и возвысил по степеням одних над другими» (Коран, 6:165). Описанные в Коране эпизоды поклонения человеку ангелами и провозглашение им имен подтверждают высокое положение человека в земной обители.

В исламе указываются следующие обязанности человека как халифа Аллаха:

- доносить до людей слово Аллаха, удерживать их от греха, заботиться о соблюдении ими заповедей;

- приумножать благосостояние и передавать его потомкам;

- давать искренние советы и наставления тем, кого он уважает, любит и ценит, а также кому желает блага; при этом делать в мягкой форме, избегая упреков;

- обладать знаниями в своей религии, чтобы быть дальновидным человеком, имеющим возможность выносить решения, когда этого требует нужда;

- обладать общественной осведомленностью – это делает его достойным выносить решения среди мусульман, не причиняя им зла [4,10, 11].

При этом есть мнение, среди ученых, что нельзя никого, кроме пророка Адама называть «наместником Аллаха», а правителей можно называть «наместниками Посланника Аллаха» [5].

Всевышний создал человека слабым, нуждающимся в опеке и защите (Коран, 4:28). Коран и Сунна раскрывают эту тайну не как недостаток, а как дар, побуждающий людей к смирению, упованию на Аллаха, милосердию, покаянию [9].

В суре «Ан-Ниса»: «Аллах хочет облегчить вам [вашу религию], ведь человек создан слабым» (Коран, 4:28). Здесь слабость объясняется как причина милосердия: Аллах не нагружает человека сверх меры, зная его природу. Шариат учитывает пределы человека, чтобы:

- он мог преуспеть в поклонении;

- вера была доступной, а не обременительной.

С рождения в человеке заложены соответствующие способности для признания веры, для ее понимания и достойной жизни. В хадисе сказано: «Каждый человек рождается согласно «фитре» (естественная предрасположенность), но позднее родители делают из него огнепоклонника, иудея или христианина» [2] сказано, что каждый ребенок появляется на свет с предрасположенностью к пониманию религии, к вере и достойной жизни.

Но после рождения, в зависимости от среды проживания, он принимает религиозную культуру своих родителей. Ребенок с момента рождения проходит через определенные стадии развития. В каждый период он имеет определенные жизненные потребности, которые нужно удовлетворить. И при удовлетворении этих потребностей высока роль религии. В определенном возрасте ребенок поймет, что чувство любви и защищенности, которое он получает от родителей, весьма ограниченно, и он устремится к безграничной любви, то есть, к Аллаху [2].

В вопросе веры или неверия в Аллаха люди обладают свободой воли. В этом нет принуждения над людьми. В Коране сказано: «Нет принуждения в (принятии) религии (ислам)...» (Коран, 2:256). Религия, апеллируя к разуму, душе и чувствам человека, делает благородными его поступки, помогает побеждать низменные желания и предлагает ему нормы жизни. Таким образом, способствует достижению в общественной и личной жизни таких качеств, которые угодны Аллаху [2].

Прославление Аллаха и благодарность за все данное Им человеку – основа поклонения (ибада). Все пророки были отправлены к людям для призыва поклоняться Богу.

Истинное поклонение возможно только при соблюдении следующих условий: человек должен верить в истинность ислама (иман), осознавать совершение действий (ният) и обладать искренностью (ихлас).

Ислам определяет четыре формы поклонения:

- духовную (вера, богобоязненность, познание Всевышнего и др.)

- телесную (молитва, пост, физическая помощь ближним и т.д.)

- материально-финансовую (закят, саадака и пр.)

- телесную и материальную (хадж) [12].

В мусульманской антропологии рассматривается вопрос, связанный с понятием «душа». В Коране есть два понятия «дух» (рух) и «душа» (нафс), сущность которых полностью постичь человек не может. В Священной книге сказано: «Дух возник по повелению моего Господа. Вам дано знать об этом очень мало» (Коран, 17:85); «Они спрашивают тебя о душе. Скажи: «Сущность души – одна из тайн Всевышнего, о которой знает только Он. И ваши знания по сравнению с Его знаниями ничтожны» (Коран, 17:85). Даже пророку Мухаммеду не дано было познать сущностность души.

Позиция ислама – Аллах вдунул в Адама из Своего Духа, поэтому у любого человека есть доля Духа: «Затем придал ему соразмерный облик, вдохнул в него от Своего духа и даровал вам слух, зрение и сердца» (Коран, 32:9). Дух (рух) человека не может допускать прегрешения. В этом его отличие от души (нафс).

Согласно мусульманскому учению Аллах создал души людей всех поколений (ушедших, современных и будущих) в одно время, заставив их произнести клятву «Аль-Мисак»: «И вывел Господь твой из хребтов сынов Адама их потомство и велел им произнести свидетельство за них, сказав: «Не Я ли – ваш Господь?». Все души ответили: «Да, Ты – наш Господь, мы свидетельствуем об этом». Чтобы в День суда вы не говорили: «Воистину, об этом мы не знали!» (Коран,7:172) [7].

Душа человека:

- способна творить и добро, и зло (Коран, 12:53, 50:16, 79:40), корить и упрекать себя (Коран, 4:110, 6:12, 6:20, 7:53, 9:42);

- во время Суда ответит за содеянное и попадет в рай или ад (Коран, 2:281, 3:25, 3:30).

Душа человека находится в постоянном изменении. Она проходит на своем пути пять уровней:

- в мире душ;

- в чреве матери;

- в земном мире;

- в могиле и в мире Барзах;

- жизнь после Судного дня.

В исламе определяют три вида нафса:

- нафс мутмаинна – мирная душа (избегает грехов);

- нафс лаввама – упрекающая душа (борется с грехами и раскаивается);

- нафс аммара – душа, побуждающая к злу (стремится к грехам) [6].

Праведность или греховность человека определяется его нафсом. Все предписания Аллаха, ниспосланные Им людям через Книги, пророков и посланников направлены на преображение души человека.

Мусульманские богословы единогласно утверждают: «основа всякого зла – покорное следование желаниям нафса, противостояние нафсу – ключ от всех благ человека» [13].

Оздоровление души осуществимо тремя способами:

- лишением нафса всех его желаний и страстей;

- нагрузкой бременем ибадата (поклонения);

- прошением помощи в борьбе против своего нафса у Аллаха.

Всевышний не даровал знание о том, из чего создана душа. Ученые ахлю сунны говорят, что душа – это тонкая материя, в отличие от грубой материи тела.

Мусульманин обязан заботиться не только о духовном здоровье, но и о телесном. Тело, дано человеку Аллахом временно, на хранение, и относиться к нему мусульманин должен с особым вниманием и лечить.

Для поддержания здоровья мусульманам рекомендуются занятия физкультурой и спортом, полноценный отдых и соблюдение личной гигиены. Благотворное влияние на здоровье верующего оказывает пост в месяц Рамадан умеренность в употреблении разрешенных продуктов (халяль), запрет на алкогольные напитки и затмевающие разум и чувства вещества.

Итак, в исламе антропологические воззрения определяются Кораном и Сунной. Человек является высшим творением Аллаха. Ислам стоит на позиции, согласно которой человек не может быть подобен Всевышнему. Процесс творения человечества охватывает два периода: создание Адама и Хавы, появление рода человеческого через естественные роды. Грех прародителей в Раю не имеет характера первородного, отразившегося на последующих поколениях людей. Человек был создан совершеннейшим, наделенным различными способностями и назначен халифом на Земле для преумножения созданных благ. Всевышний проявил милосердие, создав человека слабым, чтобы он преуспел в поклонении. Главными формами поклонения являются: духовная, материальная, материально-финансовая, совершаемая телесно и материально. Каждый человек имеет Дух и душу. Последняя склонна к греху. Душа обладает тонкой материей. Книги Аллаха, посланники и пророки несут людям Закон, исполнение которого позволяет спасти душу. Мусульманин обязан заботиться не только о духовном здоровье, но и о телесном. Смысл жизни человека определяется как познание Аллаха и поклонение Ему, чтобы достичь райского блаженства и спасения после земной жизни.

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ANTHROPOLOGICAL CONCEPTS IN CHRISTIANITY

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АНТРОПОЛОГИЧЕСКИЕ ПРЕДСТАВЛЕНИЯ В ХРИСТИАНСТВЕ

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Abstract
The article is devoted to anthropological views in Christianity. Based on the analysis of Christian theological literature, the sources of the anthropological doctrine about man are revealed; the features of God's creation of man, the fall of the first parents, and its consequences; the nature of the human soul, and the meaning of human life. It is concluded that the Christian teachings about the uniqueness of man, created in the image and likeness of God, and the redemptive sacrifice of Jesus Christ, determine the highest meaning of human life as bliss in the Kingdom of Heaven.

Аннотация
Статья посвящена антропологическим взглядам в христианстве. На основе анализа христианской богословской литературы раскрываются источники антропологического учения о человеке; особенности сотворения человека Богом, грехопадение прародителей и его последствия; природа человеческой души и смысл жизни человека. Делается вывод: христианские учения об уникальности человека, созданного по образу и подобию Божьего и искупительной жертве Иисуса Христа, определяют высший смысл жизни человека как блаженство в царстве Небесном.

Keywords: anthropology, Lord, soul, deification, Holy Scripture, Holy Tradition, body, man.
Ключевые слова: антропология, Господь, душа, обожение, Священное Писание, Священное Предание, тело, человек.

На современном этапе развития общества происходит глобальная переоценка традиционных устоев. Актуальными являются христианские антропологические представления, которые помогают осмысливать природу человека и отвечать на вызовы современности.

В условиях духовных исканий христианская антропология отвечает на вечные вопросы, связанные с сущностью человека, его происхождением, назначением, смыслом жизни, отношениями с Богом и миром.

Источниками христианской антропологии выступают Священное Предание и Священное Писание. Они дополняют друг друга, составляют единое целое и передают полноту христианского вероучения [11].

Священное Предание включает систему воззрений и традиций, которые передаются Церковью с апостольских времен через историческую преемственность. Священное Предание составляют: Священное Писание, постановления Вселенских и ряда других соборов, сочинения святых отцов и учителей Церкви, жития святых, богослужебные тексты и т.п.

Состав Священного Писания – книги, написанные богоизбранными людьми с помощью божественной благодати и под вдохновением Святого Духа.

В христианском учении человек определяется как венец творения Господа. Ему предназначалась особая роль. Всевышний поставил человека господином во Вселенной и подчинил ему все творение: «Да владычествуют они над рыбами морскими, и над птицами небесными, и над зверями, и над скотом, и над всею землею…» (Быт. 1:26).

Человек принял эту власть для того, чтобы хранить и совершенствовать созданное Богом, как в себе, так и в окружающем мире (Быт. 2: 15) с помощью божественной благодати [6].

Бог сотворил человека, чтобы тот познавал Его, любил Его, постоянно стремился к соединению с Ним и в этом находил для себя блаженство [9]. Изначальный Замысел Божий в отношении человека не изменился и после грехопадения. Путь человека к Богу лежит через исполнение Его заповедей.

Первые люди созданы Господом особенным образом, отличным от сотворения других существ.

В то время как все создания появлялись на земле от одного творческого слова «да будете», сотворение человека – следствие особого творческого акта, который состоял из двух моментов: сначала Бог образовал тело первого человека – Адама – из праха земного, а затем вдохнул в него душу. В Библии указывается: «И создал Господь Бог человека из праха земного, и вдунул в лице его дыхание жизни, и стал человек душею живою» (Быт. 2:7).

Ева была создана из ребра родоначальника всего человечества. Адам видел в Еве не просто помощника, какими для него могли быть и животные, но помощника, подобного, во многом равного ему самому: «И сказал человек: вот, это кость от костей моих и плоть от плоти моей; она будет называться женою, ибо взята от мужа [своего]» (Быт. 2:23).

Бог сотворил человека совершенным, как по душе, в умственном и нравственном отношении, так и совершенным по телу.

Человек создан по образу и подобию Божию: «И сказал Бог: сотворим человека по образу Нашему [и] по подобию Нашему» (Быт. 1:26).

Богословие раскрывает это положение следующим образом: образ – это то, что первоначально заложено Господом в человека, а подобие человек должен был приобрести благодаря благочестивой жизни [14].

Образ Божий в каждом человеке проявляется в:

- бессмертии души (ее неуничтожимости);
- разуме (способности мыслить, осознавать себя личностью и познавать Бога);
- способности к творчеству (умении творить);
- свободе воли (способности осознанно выбирать между добром и злом).

Пребывая в первозданном состоянии, человек не был склонен к злу, и до тех пор, пока не произошло его уклонение в грех, был чистым и невинным. После грехопадения образ Божий в человеке хотя и остался, но был затемнен, помутнен.

Изначально человек был сотворен потенциально бессмертным (плоды древа жизни сохраняли его от смерти). Он мог бы стать абсолютно бессмертным, если бы исполнил заповедь Божию и не согрешил. Но человек согрешил, поэтому он умирает. Теперь все люди рождаются с последствиями прародительского греха и нуждаются в Спасителе.

Для спасения человека Бог вочеловечился, принял мученическую смерть, воскрес и сделал его способным к обожению – изменению образа жизни посредством Божественной благодати. Начало обожения человека – церковная жизнь с ее таинствами, заповедями, аскетизмом, а его полнота откроется в Царстве Небесном [8, 13].

Основополагающими положениями в христианской антропологии являются:

- человек греховен в силу греха прародителей;
- человек обладает достоинством, так как создан по Образу Божьему.

Согласно христианскому учению, подлинный смысл жизни человека заключается в:

- богопознании (Ин.17:3) – получение знаний о Боге в ходе изучения Священного Предания и Священного Писания [1];
- богоуподоблении (Еф.5:1) – подражание Богу, основанное на совершении дел добра, стяжании, приумножении и развитии добродетелей осуществляемое при содействии Божественной благодати [2];
- богообщении (Ин.14:23) – общение человека и Бога посредством молитвы, восприятия Божественного Откровения, в церковных Таинствах и пр. [15].

Временные смыслами жизни для человека могут выступать выступают: дети; счастье будущих поколений; оставить что-то после себя потомкам (научные открытия, шедевры искусства); работа; удовольствия [16].

В христианской богословской литературе существуют две точки зрения по поводу состава человека:

- человек – двухсоставный – состоит из тела и души – точка зрения дихотомистов;
- человек – трехсоставный – в нем сочетаются тело, душа и дух – позиция трихотомистов.

Сторонники обеих теорий находят подтверждения своей правоты в Священном Писании. Широкую дискуссию этот вопрос в богословии не вызывал.

Библейские указания о человеке как о двухчастном существе:

- «Посему прославляйте Бога и в телах ваших и в душах ваших, которые суть Божии» (1Кор.6:20);
- «Итак, возлюбленные, имея такие обетования, очистим себя от всякой скверны плоти и духа, совершая святыню в страхе Божием» (2Кор.7:1).

Библейские выражения о трехчастном строении человека:

- «Ибо слово Божие живо и действенно и острее всякого меча обоюдоострого: оно проникает до разделения души и духа, составов и мозгов, и судит помышления и намерения сердечные» (Евр.4:12);
- «Сам же Бог мира да освятит вас во всей полноте, и ваш дух и душа и тело во всей целости да сохранится без порока в пришествие Господа нашего Иисуса Христа» (1Фес.5:23).

Взгляды святых отцов расходятся по поводу природы человеческой души.

Одни отцы утверждают ее абсолютную нематериальность. Среди них: свт. Феофан Затворник, прп. Иоанн Дамаскин, прп. Максим Исповедник. Феофан Затворник утверждает, что «Душа не образуется материальными силами, а существует отдельно от них как особое самостоятельное начало»; «Как «мысленная и непротяженная» сущность, душа не подлежит условиям пространственного ограничения» [7].

Другие ученые считают, что душа имеет особую тонкую телесность по сравнению с грубой материальностью человеческого тела. Так, свт. Игнатий Брянчанинов пишет: «Душа – эфирное, весьма тонкое, летучее тело, имеющее весь вид нашего грубого тела, все его члены, даже волосы, его характер лица, словом, полное сходство с ним…» [5].

В православном богословии нет безусловного догматического учения о происхождении души. Распространение получило мнение, согласно которому

душу человек получает, как и тело от родителей в момент зачатия, но неповторимость души формируется под непосредственным влиянием Бога. Священник Евгений Мурзин пишет, что «эта теория творения души объясняет, почему все люди несут на себя последствия грехопадения прародителей. Если бы Бог непосредственно творил каждую душу из ничего, как душу первого человека, то она бы не имела в себе тяжести первородного греха» [10].

Христианство отвергает положения о том, что души людей существуют до зачатия человека и могут реинкарнировать.

Христианская позиция – душа покидает тело человека во время смерти, предстает на частный Суд и находится в ожидании Страшного Суда, во время которого будет определена его вечная участь в зависимости от праведной или греховной земной жизни. Душа человека обладает неуничтожимостью, т.е. она не исчезает после его смерти, но она смертна у людей, которые находятся в неведении Господа: «Душа согрешающая, она умрет» (Иез.18:20) [3].

Душа, как целое, пребывает одновременно во всем теле. Об этом пишет свт. Григорий Палама: «Душа, содержа тело, с которым она вместе создана, находится в теле повсюду, а не в одном только определенном месте тела... не как охваченная им, но как содержащая, охватывающая и оживотворяющая его... Душа вездесуща в теле, как Бог в мире... как и Бог, содержит и превосходит весь мир, не содержась и не охватываясь им» [4].

В строении души святые отцы выделяют три силы (способности) – разумную (ум), раздражительную (чувства) и вожделевательную (волю).

Тело человека в силу грехопадения прародителей стало тленно. Но оно не просто оболочка души, а также участвует в обожении человека: «Тело – храм Святого Духа» (1 Кор.6:19).

О теле христианину необходимо заботиться:

- беречь как драгоценный дар;
- сохранять здоровье для служения Богу и людям;
- ограничивать свои телесные желания [12].

Тело христианину нельзя использовать в греховных целях. Во время Второго Пришествия Христа все умершие люди воскреснут.

Итак, источниками христианской антропологии являются Священное Предание и Священное Писание.

Человек определяется как венец творения Господа с предназначенной особой ролью – владычеством. Человек получил эту власть, чтобы возделывать и хранить рай, улучшать Богозданное, как в себе, так и в окружающем мире.

Бог сотворил человека, чтобы тот познавал Его, любил Его, постоянно стремился к соединению с Ним. Бог сотворил человека совершенным, как по душе, в умственном и нравственном отношении, так и совершенным по телу.

Человек создан по образу и подобию Божию, что проявляется в бессмертии души, разуме, способности к творчеству, свободе воли. После грехопадения образ Божий в человеке хотя и остался, но был помутнен. Теперь все люди рождаются с последствиями прародительского греха и нуждаются в Спасителе, который через свое человеческое воплощение, мученическую смерть и воскрешение сделал человека способным к обожению.

Подлинный смысл жизни христианина заключается в богопознании, богоуподоблении и богообщении. Согласно христианскому учению душа человека обладает неуничтожимостью и тонкой телесностью. Душу человек получает, как и тело от родителей в момент зачатия, но неповторимость души формируется под непосредственным влиянием Бога. В строении души выделяют три силы: разумную (ум), раздражительную (чувства) и вожделевательную (волю).

Тело – является орудием души, подвергшееся тлению и смерти после грехопадения человека. Всем умершим людям надлежит воскреснуть во время Второго Пришествия Христова и участвовать в жизни будущего века или вечном осуждении. В земной жизни о теле необходимо беречь как драгоценный дар и сохранять здоровье для служения Богу и людям.

Таким образом, в христианской антропологии учения об уникальности человека, созданного по образу и подобию Божьего и искупительной жертве Иисуса Христа, определяют высший смысл жизни человека как блаженство в царстве Небесном. При этом ключевое положение в христианстве – спасение возможно только в синергии свободной воли человека и Божественной благодати.

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PHYSICAL SCIENCES

EFFECT OF DOPING BSN CRYSTALS WITH MN, CE AND GD ON ELECTRICAL CONDUCTIVITY

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ВЛИЯНИЕ ЛЕГИРОВАНИЯ КРИСТАЛЛОВ БНС МАРГАНЦЕМ (Mn), СКАНДИЕМ (Sc) И ГАДОЛИНИЕМ (Gd) НА ЭЛЕКТРОПРОВОДНОСТЬ

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Abstract

This study investigates the effect of doping BSN crystals with Mn, Sc, and Gd on electrical conductivity.BSN crystals are important materials due to their ferroelectric and photorefractive properties.These materials are widely used in optoelectronics and memory devices.Doping is a common method for modifying electrical properties.Dopant elements create defect levels in the crystal lattice.These defects directly influence charge carrier behavior.Mn, being a multivalent element, creates electron trapping centers.This leads to a decrease in electrical conductivity.It also reduces the mobility of charge carriers.Sc has a more stable electronic configuration.Therefore, its effect is relatively weaker.Sc improves the structural stability of the crystal.Gd, as a rare-earth element, introduces additional fields.These fields increase the scattering of charge carriers.As a result, conductivity changes in a nonlinear manner.Temperature increase leads to changes in activation energy.This indicates a modification in the conduction mechanism.In conclusion, different dopants have distinct effects on the electrical conductivity of BSN crystals.

Аннотация

В данной работе исследуется влияние легирования кристаллов ниобата бария-стронция (БНС) примесями Mn, Sc и Gd на их электропроводность. Кристаллы БНС являются значимыми материалами благодаря своим сегнетоэлектрическим и фоторефрактивным свойствам, что обуславливает их широкое применение в оптоэлектронике и устройствах памяти. Легирование выступает эффективным методом модификации электрических характеристик данных соединений. Примесные элементы формируют дефектные уровни в кристаллической решетке, которые оказывают непосредственное влияние на поведение носителей заряда. Установлено, что марганец (Mn), являясь мультивалентным элементом, создает центры захвата (ловушки) электронов, что приводит к снижению электропроводности и уменьшению подвижности носителей заряда. Скандий (Sc) обладает более стабильной электронной конфигурацией, в связи с чем его влияние проявляется слабее и выражается преимущественно в повышении структурной стабильности кристалла. Гадолиний (Gd), как редкоземельный элемент, индуцирует дополнительные локальные поля, усиливающие рассеяние носителей заряда, что обуславливает нелинейный характер изменения проводимости. Рост темпе-

ратуры приводит к трансформации энергии активации, что свидетельствует об изменении механизмов проводимости. В заключение делается вывод о том, что различные легирующие добавки оказывают специфическое воздействие на электрофизические свойства кристаллов БНС.

Keywords: electrical conductivity, doping, ferroelectricity, intrinsic and impurity defects, BSN crystals
Ключевые слова: электропроводность, легирование, сегнетоэлектричество, собственные и примесные дефекты, кристаллы БНС (Barium Strontium Niobate).

In recent years, the practical use of ferroelectrics has increased dramatically. Therefore, the study of intrinsic and additive defects in these crystals is of great importance. In practical terms, many properties are related to structural sensitivity, that is, they depend heavily on the concentration of crystal lattice distortion. Structural sensitivity has important properties such as the value of spontaneous polarization, the stability of the monodomain state, dielectric permittivity and losses. By changing the defect subsystem of the crystal by various methods, these properties can be changed within wide limits according to the requirements. The fundamental aspect of the issue under consideration is also very important. The study of specific and impurity-defective magnetoelectrics allows us to obtain information about the mechanisms of phase transition propagation, unipolarity, and current conduction and is a general problem of solid state physics. As the object of study, single crystals of BSN (BaxSr1·xNb2O6) solid solutions obtained by the Chochralski method and doped with Mn, Ce, and Gd elements in the form of a plate cut in the direction of the magnetoelectric axis parallel to the plane with a thickness of 1.5–2.0 mm were chosen. Because, on the one hand, they have extreme values of the parameters that determine their practical application. On the other hand, they are convenient objects of research. The contacts of the samples were placed with silver paste in the direction of the polar axis and in the direction perpendicular to it. BSN crystals have structural heterogeneity. This is due both to the conditions under which the crystals were obtained and to the non-stoichiometric nature of the composition. Among oxygen-octahedral magnetoelectrics, BSN crystals have relatively high darkness and photoconductivity. In addition, their phase transition corresponds to an easily accessible temperature, which simplifies the experiment. The temperature dependences of the current were measured under conditions of temperature equilibrium of the crystal. Because pyrocurrents, which are confirmed by temperature changes, can be larger than the conduction current. In order to prevent the "aging" of the samples during the experiment, the experiment was carried out in an oxidizing environment, and the samples were not heated above 410 K in fields of 1 kV/cm. It is known that many properties of magnetoelectrics depend on the electrical conductivity. Therefore, the electrical conductivity of pure and doped BSN single crystals with elements Mn, Ce and Gd in the crystallographic direction (001) and in the direction perpendicular to it, the volt-ampere characteristics were studied. Measurements show that in pure and doped BSN crystals, when the electric field is in the direction of the polar axis, nonlinearities characteristic of the current confined by space charges are detected in the dependence of the voltage on the current. We see that for all samples in fields with an intensity of more than 300 V/cm, the volt-ampere characteristic strength is close to the dependence with n ≈ 2. In the direction perpendicular to the polar axis, the volt-ampere characteristics of pure and doped samples are close to linear (n ≈ 0.8). Based on the results of the measurements, it can be said that while Ce doping increases photoconductivity, it reduces dark conductivity, and Gd doping increases dark conductivity by about the same amount. Studies show that Mn and Ce doping does not change the activation energy and reduces dark conductivity. This indicates that self-compensation occurs during doping, as in BaTiO3. Thus, the La3+ doping replaces Ba2+ and Ti4+ ions, creating mutually compensating donors and acceptors. Doping of samples can violate the stoichiometry of their composition. Therefore, the temperature dependence of the electrical conductivity of the samples was first studied. Samples were taken with different Ba contents and oxygen vacancies. Typical dependence of electrical conductivity on temperature is given. Here, a clear exponential dependence is observed at temperatures above 400K. The activation energy was determined based on the expression σ=σ_0 exp⁡〖(-E/kT). It was found that the activation energy does not depend on the composition of the sample and is 1.4+1.5 eV. The fact that the obtained value of the activation energy is less than half of the forbidden band indicates that the conductivity is additive. The electrical conductivity becomes abnormal near the phase transition temperature, which depends on the composition of the sample. The temperature dependence of the electrical conductivity of the doped samples also shows curves for samples with a disturbed oxygen stoichiometry. The electrical conductivity values of the samples doped with Mn and Ce have close values in the studied temperature range, and the activation energy value is about 1.2 eV. The electrical conductivity of the samples doped with Gd is higher, and the activation energy is about 0.88 eV. In the temperature dependence of the phase transition curve of the samples with a disturbed oxygen stoichiometry, a low-temperature activation part is also observed before the part with an activation energy of ~1.4 eV. As the oxygen deficiency in the samples increases, the part with an activation energy of 1.4 eV disappears from the graph, and one value of the activation energy (~0.7 eV) is observed for all studied temperatures. This is also consistent with the values shown.

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SOCIAL SCIENCES

SOCIAL ANALYSIS OF THE TRANSFORMATION OF VALUES IN THE CONTEXT OF GLOBALIZATION

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Abstract

Globalization in the modern era is characterized by the intensification of social, economic, and cultural relations, and this process has a significant impact on the value system of societies. The purpose of this study is to analyze the transformation of values in the context of globalization and to determine the impact of these changes on society and the individual. Within the framework of the study, analytical and comparative approaches were used, and existing scientific literature and official statistical data on the topic were examined.

The conducted analysis shows that the process of globalization, on the one hand, creates conditions for the spread of modern values, the expansion of individual freedoms, and the increase of social opportunities; on the other hand, it is accompanied by the weakening of traditional values, changes in social relations, and the emergence of value conflicts. This transformation occurs more rapidly especially among young people and directly affects their life priorities.

From this perspective, the issue of value transformation in the context of globalization emerges as a relevant scientific problem, and this article analyzes the main directions of this process.

Keywords: globalization, transformation of values, value system, social change

MATERIALS AND METHODS

In this study, the problem of value transformation in the context of globalization was investigated based on theoretical and analytical approaches. The methodological basis of the research consists of analytical, comparative, and systematic analysis methods. Existing scientific literature, international studies, and official statistical data on the topic were analyzed [1,5].

Through the analytical method, the impact of globalization on the value system was examined from a theoretical perspective, while the comparative approach enabled the comparison of different scientific positions and approaches. The systematic approach made it possible to determine the interrelation of the social, economic, and cultural aspects of the globalization process.

The data obtained within the framework of the study were generalized, and the results were systematized and presented. The research was mainly based on qualitative methods, and the topic was analyzed from a socio-philosophical perspective.

THEORETICAL FOUNDATIONS OF GLOBALIZATION

The concept of globalization is explained in modern scientific literature as a multifaceted and complex process. The social essence of globalization is interpreted by Anthony Giddens as a "consequence of modernity," and it is noted that this process penetrates into the daily lives of individuals [9].

Although different scholars interpret this concept from various perspectives, according to the general approach, globalization is characterized by social, economic, and cultural relations transcending national borders and acquiring a global character. In social theories, globalization is evaluated as the intensification of intersocietal relations, the acceleration of information exchange, and the transformation of individuals into components of the global system [5].

One of the main characteristics of globalization is the increase in interdependence. As a result of this process, economic, political, and social relations between different countries and societies become more intensive. At the same time, globalization leads to the acceleration of social change, the formation of new values, and the transformation of existing social structures [7]. In particular, the development of information technologies further accelerates the globalization process and directly affects individuals' worldview and social behavior.

TRANSFORMATION OF VALUES

The process of value change is explained by Ronald Inglehart in the context of modernization and postmodernization and is evaluated as a transition from material values to post-materialist values [10].

In the context of globalization, the transformation of values acts as a multidimensional and dynamic process. These changes are formed as a result of the interaction of social, economic, and cultural factors. As a result of economic development and the expansion of market relations, values such as material well-being, career, and economic success come to the forefront and directly affect individuals' life priorities [8].

On the other hand, intercultural interaction leads to a certain degree of change in traditional values and the formation of new value models. Under the influence of global culture, national and moral values weaken in some cases, while in other cases they are reshaped according to new conditions [6]. This process is especially clearly observed in family relations, social behavior norms, and communication culture.

Thus, the transformation of values is evaluated as a complex social process that can produce both positive and negative outcomes.

YOUTH AND VALUES

Modern youth are among the most active participants in the globalization process and, at the same time, one of the social groups most affected by it. The expansion of the global information environment, the spread of social networks, and the rapid development of technology have a significant impact on the thinking style, behavior, and life priorities of young people.

Studies show that among young people there is a change in forms of communication, a transition of social relations more into the virtual environment, and an increase in orientation toward material values [8]. These changes are among the important factors affecting their socialization process and personality formation.

At the same time, socio-economic problems, especially unemployment and uncertainty about the future, affect the psychological state of young people and play an important role in shaping their life priorities [1]. However, it should be noted that among modern youth there are also individuals with high intellectual capacity, openness to innovation, and beneficial activities for society. This shows that globalization has not only negative but also positive effects.

AZERBAIJAN CONTEXT

The process of globalization has also led to social and cultural changes in Azerbaijani society. Especially in recent years, the development of information technologies, the expansion of international relations, and reforms in the field of education have influenced the value system of society.

According to official statistical data, certain changes have been observed in the education level, employment opportunities, and social behavior indicators of young people [1,2]. These changes directly affect their lifestyle, worldview, and value system.

At the same time, a certain interaction and sometimes contradiction between traditional values and modern approaches are observed in Azerbaijani society. This makes the issue of preserving national and moral values more aktyal in the context of globalization.

In this regard, ensuring a balance between the adoption of modern values and the preservation of national values is of great importance for the sustainable development of society.

DISCUSSION

Changes in social relations in modern society and the increase in distance between individuals are explained by Zygmunt Bauman through the concept of "liquid modernity" [11].

The analysis shows that the transformation of values in the context of globalization is not linear and one-sided, but rather multifaceted and contradictory. On the one hand, global processes create conditions for the expansion of individual freedoms, increased access to information, and broader social opportunities [5]. On the other hand, these changes are accompanied by the weakening of traditional values, the superficialization of social relations, and the increase in distance between individuals [6].

The changes observed especially among young people show that this process has a more dynamic and sensitive character. As a result of the influence of social networks, the transformation of technology into an integral part of daily life, and the strengthening of economic factors, shifts in value priorities among young people are observed [8]. This sometimes leads to contradictions between moral values and material interests.

On the other hand, globalization is not limited only to negative consequences. It plays a positive role in acquiring new knowledge, expanding intercultural dialogue, and increasing opportunities for self-development. From this perspective, the transformation of values should be evaluated more as a process of adaptation and reformation.

In the context of Azerbaijani society, this process requires special sensitivity in terms of both preserving traditional values and adopting modern development trends. This further increases the role of social policy, the education system, and public awareness. In this regard, the globalization process can also be associated with the formation of a "risk society," as noted by Ulrich Beck [13].

Thus, the transformation of values in the context of globalization is not only a social change but also a complex process accompanied by individuals' search for identity. In this context, the preservation and renewal of values must be carried out simultaneously.

CONCLUSION

Thus, the transformation of values in the context of globalization is an integral part of the development of modern society. This process directly affects individuals' worldview, social relations, and life priorities. The results of the study show that although changes in values are inevitable, the direction and content of these changes depend on the social and cultural characteristics of society.

In the modern period, the main task is to ensure the preservation of national and moral values while effectively utilizing the opportunities created by globalization. For this purpose, it is considered important to strengthen a value-oriented approach in the education system, increase the sense of social responsibility among young people, and create a healthy value environment within society.

As a result, the transformation of values should be evaluated not only as a change but also as the emergence of new development opportunities. Proper management of this process is one of the main conditions for sustainable and balanced development of society.

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TECHNICAL SCIENCES

INFLUENCE OF FORMATION MODES ON THE PROPERTIES OF FIBROUS MATERIALS BASED ON POLYPHENYLENE SULFIDE

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Abstract
The influence of a functional additive and formation conditions on the properties of filter fibrous materials based on blends of polyphenylene sulfide and polypropylene was studied. It was shown that with increasing polypropylene content in the blend, the average fiber diameter increases. The presence of a dispersed additive contributes to a slight increase in fiber diameter, while additional heat treatment leads to an even greater increase. It was found that the introduction of a dispersed additive leads to an increase in the degree of material crystallinity, and changes in the physical and mechanical properties: sample shrinkage decreases and their rigidity increases.

Keywords: polyphenylene sulfide, fiber diameter, degree of crystallinity, filtration efficiency, transmittance, shrinkage

Purification of liquids and gases is an integral part of both most industrial processes and everyday human life. The presence of large quantities of impurities in the environment, whether liquid or solid, degrades the performance of devices and subsystems, reducing their overall service life and efficiency, and also negatively impacts the health of living organisms and the environment when contaminated media come into contact with the biosphere. Inclusions up to several tens of micrometers in size are the most difficult to remove from submeter-velocity flows and constitute the bulk of the total contaminant mass, which has a negative impact on mechanisms and the human body [1].

The most effective and, at the same time, cost-effective method of filtering this type of contamination from media is the use of non-woven polymer fibrous-porous materials, whose large specific surface area and mechanical properties meet modern purification requirements [2]. A sufficiently wide range of fiber-forming polymers allows for flexible variation of the characteristics of the resulting products and the selection of the necessary solution based on purification requirements. Polyolefins are most frequently used as they are widely available and inexpensive materials that are easy to process and subsequently dispose of [3-5].

To purify media characterized by high temperatures or aggressiveness to "classic" filter polymers, materials with a more complex chemical structure are used, in particular polyphenylene sulfide. However, often, when non-trivial tasks arise involving the separation of liquid or solid contaminants, pure polymeric materials cannot provide the required filtration efficiency. In such cases, functional additives are introduced into the polymer bulk, designed to change the nature of the interaction at the phase boundary and, as a result, improve the filtration properties of the spatial structure of the microfibers. In addition, the properties of fibrous materials are significantly affected by technological processing modes, in particular, additional heat treatment or exposure to strong electric fields [6]. However, there is no consensus on the influence of external factors directly affecting the production of such products [7].

The aim of this work is to investigate the influence of functional additives and formation modes on the properties of filter elements made of fibrous materials based on mixtures of polyphenylene sulfide and polypropylene.

This study utilized materials produced by meltblowing. Meltblowing (*MB*) is a simple, versatile, and widely used extrusion-based technology that generates continuous nano/microfibers, typically forming a randomly oriented web [8]. *MB* fiber products (in the form of mats or cylinders) are formed directly from molten polymer without controlled stretching. The optimization criterion for the process conditions is achieving the best performance characteristics of *MB* materials. All other things being equal, these characteristics depend on two structural parameters: the fiber diameter d and the density ρ (or porosity) of the fibrous framework.

In this work, we investigated the effect of a nano dispersed filler, as well as additional IR and heat treatment, on the purification efficiency and physic mechanical properties of fibrous-porous filter materials (FPFM) obtained by melt blowing from mixtures of polyphenylene sulfide (PPS) and polypropylene (PP). The samples were made in the form of cylindrical filter elements obtained under the same operating conditions of the extrusion equipment. Dispersed nano clay – montmorillonite (MMT) with a particle size of 3–5 nm and a content of 0.1 wt. % in the mixture was used as a modifying filler. Such a low filler content is due to the

technological difficulties of forming an air-polymer torch when spraying the melt. Heat treatment of the samples was carried out in an oven at a temperature of 150 °C for 4 hours, a ceramic infrared emitter IKN-101 manufactured by NOMACON ODO (Belarus) was used as an IR emitter.

Six groups of PPS-based samples with different PP contents (wt.%) were studied: 0; 2.5; 5.0; 7.5; 10; 15. Within each group, the samples differed in the presence or absence of a modifier and heat treatment. The average fiber diameter was determined using a MED D45T optical microscope (Levenhuk Optics Ltd., USA), the degree of crystallinity was determined by differential scanning calorimetry on a DSC 214 Polyma device (Netzsch – Gerätebau GmbH, Germany). Filtration efficiency and transmittance were determined on a SIGF-1 stand (LLC Scientific and Technical Center LARTA, Belarus). In addition, the degree of shrinkage (relative change in the length of a cylindrical sample after heat treatment) and the depth of steel indenter penetration into the sample material were determined.

The results of the study are presented on the table.

It is evident that with increasing PP content, the average fiber diameter increases (from 33 to 47 μm), with the presence of MMT contributing to a slight increase in fiber diameter, and additional heat treatment leading to an even greater increase. The increase in fiber diameter with increasing PP content in the blend is explained by its higher MFI (< 6 g/10 min) than that of PPS (> 30 g/10 min). The presence of dispersed particles in the melt somewhat reduces melted flowability, leading to an increase in fiber diameter.

The degree of crystallinity of the samples changes slightly depending on the PP content in the mixture. However, it is noteworthy that in each group, an increase in the degree of crystallinity of the samples is observed with the introduction of dispersed filler. This indicates that the filler particles, even at such low concentrations, initiate crystal formation.

Filtration efficiency is quite high for samples in all groups; however, it is not possible to establish a pattern in how this indicator varies depending on melt composition and the presence of heat treatment. Filtration efficiency can be indirectly assessed by the particle transmission coefficient, which also varies slightly depending on the melt component content and the presence or absence of heat treatment.

Significant differences are observed in physical and mechanical properties. Firstly, low shrinkage is observed for all types of samples based on PPS and PP blends. Secondly, the presence of MMT in the mixture after heat treatment of the samples further reduces shrinkage (e.g., samples 7, 8, 11, 12). Moreover, the rigidity of these samples increases significantly. For example, the indenter penetration depth for samples 4, 7, 8, 11, 12, 15, 16, and 18 is 0.96–5.5 mm, compared to samples made from PPS+PP blends (17.4–22.0 mm).

Conclusion

Thus, as a result of studying the influence of functional additive and formation modes on the properties of filter fibrous materials based on blends of polyphenylene sulfide and polypropylene, the following was established:

– with increasing polypropylene content in the blend, the average fiber diameter increases, with the presence of a dispersed additive contributing to a slight increase in fiber diameter, and additional heat treatment leading to an even greater increase;

– the degree of crystallinity of the samples changes slightly depending on the PP content in the blend; however, in each group, an increase in the degree of crystallinity of the samples is observed with the introduction of a dispersed filler;

– all types of samples based on PPS and PP blends exhibit low shrinkage; the presence of MMT in the blend after heat treatment of the samples further reduces shrinkage, while the rigidity of these samples increases significantly.

Table

Sample characteristics

Samples			*d*, μm	Cryst.%	Ef., %	*K*, %	Δ*l*/*l*, %	*h*, mm
Group	Number	Composition						
1	1	Pure PPS	33	36	87,79	0,1422	-	22
	2	Pure PPS + Heat treatment	34		**81,92**	**0,2094**	**15,0**	**2,1**
2	3	PPS+2.5% PP	36		86,75	0,1492	-	18,5
	4	PPS+2.5% PP + Heat treatment	37		**87,80**	**0,1391**	**4,22**	**2,2**
3	5	PPS+5% PP	34	39	90,56	0,1136	-	18,8
	6	PPS+5% PP +*MMT*	38	41	87,84	0,1532	-	18,1
	7	PPS+5% PP + Heat treatment	34		**88,07**	**0,1279**	**2,68**	**4,0**
	8	PPS+5% PP +*MMT* + Heat treatment	41		**85,15**	**0,1690**	**0,96**	**3,9**
4	9	PPS+7.5% PP	38	37	88,11	0,1335	-	18,8
	10	PPS+7.5% PP +*MMT*	41	40	80,31	0,2276	-	18,4
	11	PPS+7.5% PP + Heat treatment	40		**86,74**	**0,1541**	**1,82**	**3,0**
	12	PPS+7.5% PP +*MMT* + Heat treatment	44		**79,20**	**0,2337**	**1,57**	**3,6**
5	13	PPS+10% PP	37	37	82,85	0,1927	-	20,5
	14	PPS+10% PP +*MMT*	42	42	88,77	0,1377	-	18,3
	15	PPS+10% PP + Heat treatment	39		**81,86**	**0,2049**	**0,86**	**3,6**
	16	PPS+10% PP +*MMT* + Heat treatment	43		**78,29**	**0,2318**	**1,11**	**5,1**
6	17	PPS+15% PP	47		88,31	0,1323	-	17,4
	18	PPS+15% PP + Heat treatment	49		**85,31**	**0,1702**	**0,31**	**5,5**

Designations: *d* – average fiber diameter; Cryst. – degree of crystallinity, Ef – filtration efficiency with respect to particles ≥ 10 μm in size; *K* – transmission coefficient of contaminant particles; Δ*l*/*l* – relative change in the length of a cylindrical sample after heat treatment (shrinkage); *h* – indenter penetration depth at a temperature of 150 °C and a pressure of 0.2 MPa

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FEASIBILITY JUSTIFICATION FOR A HYBRID ULTRASONIC FLOWMETER FOR NATURAL GAS

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Abstract

The possibility of creating a hybrid ultrasonic flowmeter of natural gas is presented, which combines a four-channel ultrasonic transit-time method (TOF) and a resonance method. A mathematical description of such a flowmeter is given, the errors of the classical and the proposed flowmeter are estimated, the gain in accuracy and resistance to external factors are shown.

Keywords: ultrasonic flowmeter; natural gas; transit-time method; resonance method; hybrid measurement; speed of sound; measurement error; gas metering.

Introduction

At present, ultrasonic flowmeters are high-precision means for measuring the flow rate of liquids and gases in industrial and scientific applications [1]. Their main advantages are the absence of moving parts, operation in a wide range of operating conditions, low losses and high speed. In commercial metering tasks, the norms of relative error are currently at the level of ±(0.5–1.0) % or lower [2–4].

Classical ultrasonic natural gas flowmeters are based on the transit-time method (TOF). Their error significantly depends on the speed of sound c, temperature T, pressure P, as well as the velocity profile. For an inclined beam (angle θ), the flow velocity along the i-th beam is determined as

$$1)\ \boldsymbol{v_i} = \frac{L_i}{2\cos\,\theta}\left(\frac{1}{t_{i,\uparrow}} - \frac{1}{t_{i,\downarrow}}\right), \qquad \textbf{(1)}$$

where:

L_i- pipe diameter ;

$t_{i,\uparrow}$- signal transit time against the flow;

$t_{i,\downarrow}$- signal transit time along the flow.

Transit times depend on the speed of sound c, which is calculated by a known formula taking into account the real properties of the gas:

$$\boldsymbol{c} = \sqrt{\frac{\gamma RTZ(p)}{M}},$$

where:

γ — adiabatic index (ratio of heat capacities C_p/C_v);

R — universal gas constant (R=8.314 J/(mol·K));

T — thermodynamic temperature of the gas (in Kelvin);

Z(P) — gas compressibility factor, which takes into account deviation from the ideal gas; depends on pressure P;

M — molar mass of the gas (kg/mol).

In a multi-channel system, for example a four-channel one, if the channels are arranged

symmetrically, equal weights are used, i.e.

$$\boldsymbol{w_i} = \frac{1}{4}, \boldsymbol{i} = \boldsymbol{1,2,3,4},$$

then the average velocity is calculated as

$$\boldsymbol{v_{\text{avg}}} = \frac{1}{4}\sum_{i=1}^{4} \boldsymbol{v_i}.$$

Thus, in standard formulas, as we can see, c and v are calculated using the same time parameters $\boldsymbol{t_{i,\uparrow}}$ and $\boldsymbol{t_{i,\downarrow}}$. Any systematic error in time measurement (for example, synchronization error, signal delays) simultaneously distorts both results - both the flow velocity and the calculated speed of sound. In a pipeline at high pressure or deviation from ideal gas, the speed of sound changes. This is especially manifested during the transition from laminar to turbulent flow regime. The gas composition is not ideal, temperature gradients take place. In addition, gas effects associated with pressure are observed. Theoretical formulas, as noted, often use averaged values, which, although reduce the total error, in some cases it may also increase. Thus, errors arise because the nominal value of c is used, which does not correspond to real conditions. Therefore, recently in scientific articles new measuring converters appear, which simultaneously use several methods and, accordingly, several informative parameters of the ultrasonic signal. This makes it possible to perform so-called cross measurements. The most well-known example of a hybrid TOF+Doppler flowmeter is the Duosonics system from Fuji Electric, which combines (TOF) and Pulse Doppler methods. Also, in scientific literature, studies of Kobe University are described, where the TOF method is calibrated using an ultrasonic Doppler velocity profile (UDV). The TOF method measures the average linear flow velocity. The ultrasonic pulse Doppler method (UDM) provides data on the flow velocity profile and allows estimating local flow velocities [5].

The combination of methods increases the accuracy and reliability of measurements in complex flows – turbulent, aerated, with impurities.

In this work, the possibility of creating a hybrid ultrasonic flowmeter, which would combine the TOF and resonance method, is considered. The development of such a flowmeter is the purpose of the work.

Research results

The scheme of the proposed hybrid ultrasonic flowmeter combines TOF and resonance method (RES) [6]. Fig. 1 shows the scheme of spatial arrangement of the flowmeter channels, four pulse channels of which operate according to the TOF method and are located at an angle to the flow. The fifth channel is located perpendicular to the flow and operates according to the resonance method. The scheme of the hybrid flowmeter is designed in the SOLIDWORKS Flow Simulation environment.

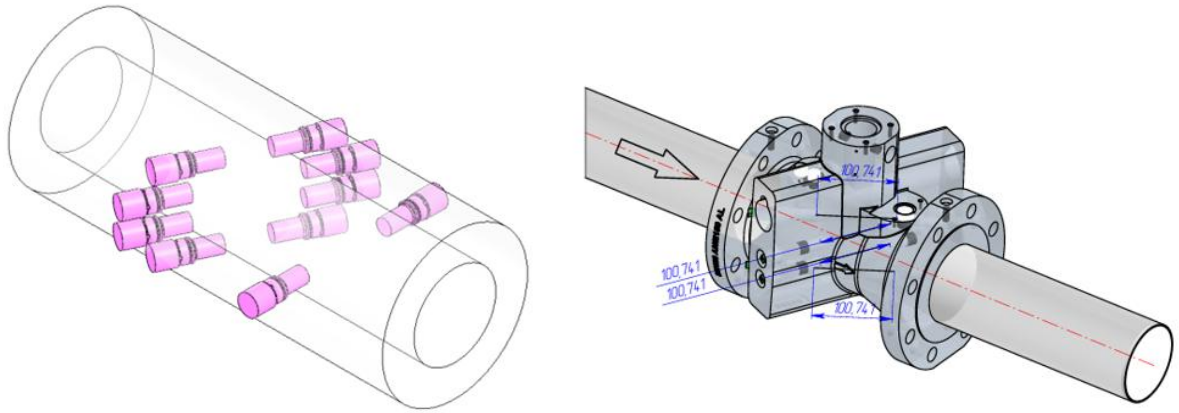

Fig. 1. Scheme of arrangement of channels of the hybrid ultrasonic flowmeter designed in the SOLIDWORKS Flow Simulation environment

For what purpose was the resonance channel applied? The resonance method operates on another physical principle or uses another measurement configuration, providing an independent source of data about c. This allows the system to cross-check the results. At the same time, resonance methods have higher sensitivity to small changes in acoustic impedance or medium density than pulse methods, especially in media with high attenuation (gas, vapor), and can also control temperature. In addition, with this approach, the reliability of the entire measurement system is significantly increased. If the value of c obtained from pulse channels suddenly differs from the value of c obtained from the resonance channel, this is an indicator of a problem: either one of the sensors is clogged/faulty, or bubbles or impurities have appeared in the flow. In real conditions, the gas mixture may contain impurities, moisture, CO_2, CH_4, etc.

Thus, the proposed scheme is more reliable, makes it possible to obtain additional redundant information, which makes the final result — flow measurement — more resistant to errors arising under the influence of external factors. This means that in this case the flow velocity will be determined using an additional correction function, which is introduced into formula (1) and we obtain the expression

$$\boldsymbol{v_i} = \frac{L_i}{2\cos\,\theta}\left(\frac{1}{t_{i,\uparrow}} - \frac{1}{t_{i,\downarrow}}\right) \cdot \boldsymbol{K_{nl}(c)}\,, \qquad \textbf{(2)}$$

where: $K_{nl}(c)$ — correction coefficient.

The correction coefficient is introduced to match the real speed of sound c_real with the nominal c_nom used in the basic flow formula. Then:

$$\boldsymbol{K_{nl}(c)} = \frac{\boldsymbol{c_{real}}}{\boldsymbol{c_{nom}}} \qquad \textbf{(3)}$$

The real speed of sound can be determined by the formula:

$$\boldsymbol{c_{real}} = \frac{\boldsymbol{2Lf_{res}}}{\boldsymbol{n}} \qquad \textbf{(4)}$$

where:

n — harmonic number;

f_{res} — resonance frequency of the resonator.

Then the flow velocity will be determined taking into account formulas (2)–(4) as

$$\boldsymbol{v_m} = \frac{L}{2\cos\,\theta}\left(\frac{1}{t_{i,\uparrow}} - \frac{1}{t_{i,\downarrow}}\right) \cdot \frac{2Lf_{res}}{nc_{nom}}\,. \qquad \textbf{(5)}$$

Thus, a resonator at ultrasonic frequency can be integrated into a hybrid flowmeter as a correction module of the speed of sound, which operates by analogy as TOF plus UDM. This provides a more accurate and stable measurement system [7].

We perform an analysis of errors for the classical and the proposed flowmeter. Let us denote the relative error as $\boldsymbol{\delta v} = \frac{\Delta v}{v}$.

For the classical model: $\boldsymbol{v_{TOF}} \sim \boldsymbol{c^2 \cdot \Delta t}$. Then the error of the classical scheme will be determined as

$$\boldsymbol{\delta v_{TOF}} \approx \boldsymbol{2\frac{\Delta c}{c} + \frac{\Delta L}{L} + \tan\theta\Delta\theta + \delta_t}.$$

In this case $\boldsymbol{\delta_t} = \frac{\Delta t_{i,\uparrow}}{t_{i,\uparrow}}\frac{t_{i,\downarrow}}{t_{i,\downarrow}-t_{i,\uparrow}} + \frac{\Delta t_{i,\downarrow}}{t_{i,\downarrow}}\frac{t_{i,\uparrow}}{t_{i,\downarrow}-t_{i,\uparrow}}$.

After rounding we obtain that $\boldsymbol{\delta_t} \approx \frac{\Delta t}{\Delta t_{diff}}$.

Let us consider the errors of the proposed scheme. For this, we represent formula (5) as

$\delta\boldsymbol{v_m} = \mathbf{A} \cdot \mathrm{B}$, where $\boldsymbol{A} = \frac{L}{2\cos\,\theta}\left(\frac{1}{t_{i,\uparrow}} - \frac{1}{t_{i,\downarrow}}\right), \boldsymbol{B} = \frac{2Lf_{res}}{nc_{nom}}$.

Then the total relative error for the product will be determined by the sum

$$\boldsymbol{v} = \boldsymbol{\delta A} + \boldsymbol{\delta},.$$

$$\boldsymbol{\delta}\mathrm{A} \approx \frac{\Delta \mathrm{L}}{\mathrm{L}} + \boldsymbol{\tan\theta\Delta\theta + \delta_t},.$$

$$\boldsymbol{\delta}\mathrm{B} = \frac{\Delta \mathrm{L}}{\mathrm{L}} + \frac{\Delta \mathrm{f}}{\mathrm{f}} + \boldsymbol{\tan\theta\Delta\theta} - \frac{\Delta c_{nom}}{c_{nom}}.$$

The total error of the scheme will take the form:

$$\boldsymbol{\delta v_m} \approx \boldsymbol{2\frac{\Delta t}{t} + \frac{2\Delta f_{res}}{f_{res}} + \frac{\Delta L}{L} + \tan\theta\Delta\theta}$$

If we assume that c_$\boldsymbol{c_{nom} = const}$ (calibration) and the geometry does not change, we obtain a simplified expression of measurement error:

$$\delta v_m \approx \delta_t + \frac{\Delta f_{res}}{f_{res}}.$$

Based on the obtained dependencies, the following conclusions can be made: the classical TOF has a high dependence on the speed of sound (~c²), the error is mainly determined by $2\delta c + \delta t$. At the same time, the influence of temperature and gas composition is quite high, which requires the use of temperature and pressure sensors. In the hybrid TOF+RES the dependence on the speed of sound and gas composition is compensated, the influence of temperature is much smaller, the error is mainly determined by time and frequency parameters $\delta t + \delta f$. Thus, in the classical TOF the speed of sound is the source of the main error, and the hybrid model eliminates the error from the speed of sound.

We perform a numerical calculation of errors for two schemes using generally accepted values of relative errors of components of the total error.

For the classical flowmeter: $\delta c/c = 1\%$; $\delta(\Delta T)/\Delta T = 0.5\%$, but averaging due to 4 channels - $5\%/\sqrt{4} = 0.25\%$; $\delta L/L = 0.2\%$; $\delta(\cos\theta)/\cos\theta = 0.1\%$; $\delta t = 0.1\%$.

Then the total relative error is:

$$\frac{\delta v}{v} \approx 2 \cdot 1\% + 0.25\% + 0.2\% + 0.1\% + 0.1\% \approx 2.65\%.$$

For the hybrid flowmeter, the error $\delta c/c$ is much smaller, since c is measured by f_0. For example, $\delta c/c \approx 0.01\%$ (frequency meter provides very high resolution). Other errors are the same.

Then:

$$\frac{\delta v}{v} \approx 0.2\% + 2 * 0.1\% + 0.25\% + 0.2\% + 0.1\% \approx 0.85\%.$$

Thus, the hybrid TOF+RES method reduces the total relative error approximately from **2.65%** to **0.85%** mainly due to replacing the dominant uncertainty of the speed of sound and a much smaller error of the resonance frequency.

How does the measurement error change with a change in the speed of sound? For a classical flowmeter, the change in velocity is proportional to the change in flow velocity, i.e. $\frac{\delta v}{v} \approx \frac{\delta c}{c}$. For a hybrid flowmeter, such dependence is absent. This means that with a relative change in the speed of sound, the error remains practically unchanged. Fig. 2 shows the graph of dependence of the relative error on the relative change in the speed of sound in the range (−0.1;0.1).

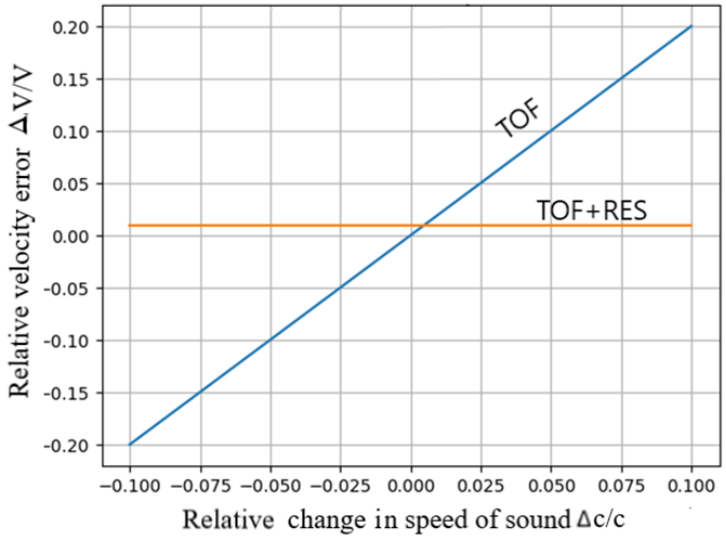

Fig. 2. Graph of dependence of relative error on relative change of speed of sound for classical and hybrid flowmeter

An increase in the relative change of the speed of sound is observed in transitional and turbulent regimes. This means that in such regimes the relative error of the classical flowmeter increases as shown in Fig. 3, which is not observed in the hybrid one. This is the advantage of the proposed flowmeter. The remaining errors are mainly determined by the accuracy of time and frequency measurements.

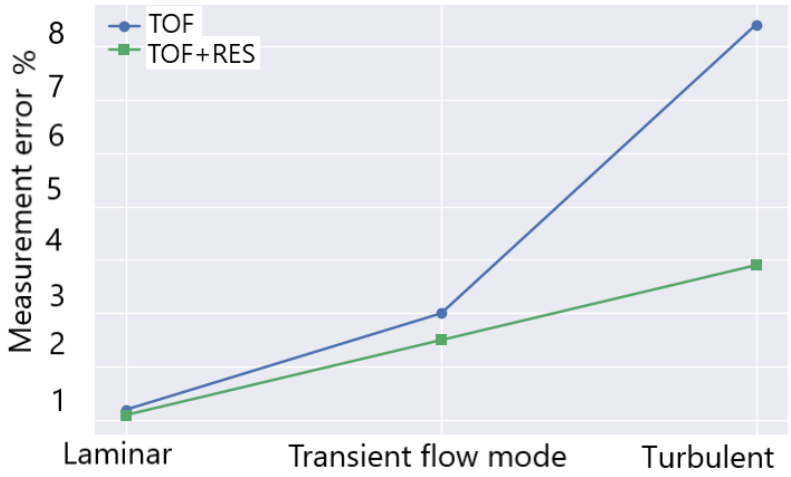

Fig. 3. Dependence of measurement error when changing gas flow regimes

Thus, the resonator at ultrasonic frequency can be integrated into a hybrid flowmeter as a correction module of the speed of sound, operating by analogy as TOF + Doppler method. This provides a more accurate and stable measurement system.

Conclusions

The proposed mathematical model of a hybrid ultrasonic flowmeter combining the TOF method with the resonance method, which measures the speed of sound. This makes it possible to perform cross measurements, but at the same time redundancy in the system is obtained. The errors of flowmeters are estimated, their numerical values are obtained, which answer what the advantages of the hybrid device are. Unlike classical TOF flowmeters, the proposed approach allows eliminating the influence of changes in the speed of sound on the measurement result, which significantly increases accuracy under varying thermodynamic conditions. This provides a reliable and more accurate and stable self-calibrating measurement system.

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ABOUT THE CAUSES OF DEFORMATION ON PUBLIC ROADS

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О ПРИЧИНАХ ОБРАЗОВАНИЯ ДЕФОРМАЦИЙ НА АВТОМОБИЛЬНЫХ ДОРОГАХ ОБЩЕГО ПОЛЬЗОВАНИЯ

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Abstract

The article discusses the main causes of deformations and damage on public roads during their operation. The physicochemical processes of bitumen aging, including evaporation of volatile components, oxidation, polymerization, and polycondensation, which occur under the influence of temperature, oxygen, moisture, and solar radiation, are analyzed. Special attention is paid to the influence of traffic loads and natural and climatic factors on the reduction of road surface strength. The most common types of defects are described: cracks, ruts, potholes, subsidence, wave formation and peeling, as well as the causes of their occurrence. The results of experimental studies on the determination of the modulus of elasticity of the layers of pavement using the press-stamp method are presented. It has been established that humidity and temperature conditions, the heterogeneity of the base and the discrepancy between the structural parameters of the road and the actual traffic loads have a significant impact on the development of deformations.

Аннотация

В статье рассмотрены основные причины образования деформаций и разрушений на автомобильных дорогах общего пользования в процессе их эксплуатации. Проанализированы физико-химические процессы старения битума, включая испарение легколетучих компонентов, окисление, полимеризацию и поликонденсацию, происходящие под воздействием температуры, кислорода, влаги и солнечной радиации. Особое внимание уделено влиянию транспортных нагрузок и природно-климатических факторов на снижение прочности дорожных покрытий. Описаны наиболее распространённые виды дефектов: трещины, колейность, выбоины, просадки, волнообразование и шелушение, а также причины их возникновения. Представлены результаты экспериментальных исследований по определению модуля упругости слоёв дорожной одежды с использованием метода пресс-штампа. Установлено, что существенное влияние на развитие деформаций оказывают влажностно-температурные условия, неоднородность основания и несоответствие конструктивных параметров дороги фактическим транспортным нагрузкам.

Keywords: highways, road clothing, asphalt concrete, deformations, cracks, ruts, potholes, bitumen aging, modulus of elasticity, transport loads, climatic factors, coating strength.

Ключевые слова: автомобильные дороги, дорожная одежда, асфальтобетон, деформации, трещины, колейность, выбоины, старение битума, модуль упругости, транспортные нагрузки, климатические факторы, прочность покрытия.

В процессе эксплуатации автомобильной дороги асфальтобетонное покрытие постепенно утрачивает первоначальные свойства: снижается фрикционная способность, ухудшается ровность, появляются трещины, выбоины, наплывы, волны, просадки и колейность. Происходит старение битума вследствие сложных структурных и химических превращений под влиянием воздействия на материал различных факторов. На тонкий слой битума оказывают влияние кислород и температура воздуха, вода, состояние поверхности минерального материала. При этом скорость старения асфальтобетона зависит от его остаточной пористости.

По данным В. В. Михайлова и А. С. Колбановской к изменению состава свойств битума приводят следующие процессы [1]:

а) испарение масел, происходящее в поверхностном слое битума незначительной толщины и зависящее от содержания в нем легколетучих компонентов, вязкости и температуры;

б) оксиполимеризация и частичная полимеризация компонентов битума, главным образом на

внешней поверхности вяжущего, подвергающегося непосредственному воздействию света и ультрафиолетовых лучей;

в) поликонденсация, происходящая под влиянием кислорода. Кислород воздуха вызывает нарушение структуры битума и приводит к увеличению его молекулярной массы. Битум от соприкосновения с воздухом окисляется, а под лучами солнца эти окислительные процессы протекают более энергично в результате нагревания покрытия и фотохимических реакций.

Причины образования дефектов [3]**.** *Износ* покрытия происходит под влиянием касательных сил, действующих в плоскости следа автомобильных колес и вызванных работой шин по преодолению сил трения. Касательные напряжения в плоскости следа вызывают истирание дорожного покрытия и покрышки колеса автомобиля на всем пути его следования. Такие напряжения увеличиваются от комплекса воздействий, вызывающих проскальзывание покрышки колеса в плоскости следа в условиях нормального его качения. Кроме того, усилению износа способствуют природные факторы, так как материал покрытия ослабляется при насыщении водой, а зимой под действием ее замерзания.

Износ покрытия происходит по все ширине проезжей части, но больше всего на полосах наката, где чаще проходят колеса автомобилей в один след. При исследованиях условно принимают величину износа равномерно распределенную по всей площади покрытия. При этом средняя величина износа $h_{ср}$, мм, составляет:

$$h_{ср}=k\cdot h_{н}, \quad (1)$$

где k – коэффициент неравномерности износа, в среднем составляющий величину 06-07; $h_{н}$ – определенная величина износа на полосе наката, мм.

Одним из видов деформаций, влияющих на прочность дорожных покрытий, является *шелушение.* Оно происходит тем интенсивнее, чем выше пористость и меньше прочность материала покрытия. Процесс шелушения развивается также от действия хлоридов, применяемых при борьбе со скользкостью. Особенно вредны они для цементобетонных покрытий с большим содержанием поверхностных пор.

Обычно после шелушения начинается процесс *выкрашивания* покрытий, при котором от покрытия отделяются более крупные зерна минерального материала. Причинами выкрашивания покрытий служит также низкое качество смесей из-за перевозки их в самосвалах (остатки песка попадают в покрытие), недоукатки покрытия в холодную и дождливую погоду и т.п. Приостановить этот процесс можно путем укладки защитного слоя.

Обламывание кромок происходит в случаях переезда тяжелых грузовых автомобилей через кромку покрытия (рисунок 1, а). На цементобетонных покрытиях, кроме того, кромки обламываются вдоль температурных швов при низком качестве бетона или когда нет связи между плитами.

а) *б)*

Рис. 1. Обломка кромок (а), поперечные и продольные (б) трещины

Волнообразование происходит за счет излишней пластичности покрытия. Верхний слой асфальтобетонных покрытий под воздействием касательных сил, особенно при торможении, сдвигается на уклонах и в местах остановок общественного транспорта. Волны, или складки, образуются преимущественно в жаркую солнечную погоду, когда покрытие нагревается до 60° и более.

Продольные трещины возникают при неоднородно уплотненном земляном полотне – когда края его, уплотненные меньше середины, начинают давать осадки. Косые трещины появляются над местными пустотами – осадками земляного полотна и при недостаточно прочных покрытиях (рисунок 1, б).

Сетка трещин возникает на дорожном покрытии, как правило, при недостаточной прочности слоев основания. Особенно часто сетка трещин образуется в весенний период, когда переувлажненный грунт вызывает под нагрузкой большие прогибы основания. Более жесткий материал покрытия не выдерживает таких прогибов, в результате чего и появляются трещины (рисунок 2, а).

Просадки – деформации дорожной одежды в виде впадин глубиной 50-100 мм и более с пологой поверхностью, но без выпучивания и образования

трещин на прилегающих участках. Возникают в местах пониженной прочности слоёв одежды и грунта при увлажнении (рисунок 2, б). Просадки могут наблюдаться в первые годы эксплуатации дороги, при неблагоприятных грунтово-гидрологических условиях, вследствие недостаточного уплотнения земляного полотна и слоёв одежды, а также при появлении в составе движения тяжёлых автомобилей, на которые дорожная одежда не была рассчитана.

а) *б)*

Рис. 2. Сетка трещин (а) и просадки (б)

Колеи образуются в основном на покрытиях переходного типа на сравнительно узких проезжих частях при движении автомобилей след-в-след и при ослабленном основании (рисунок 3, а).

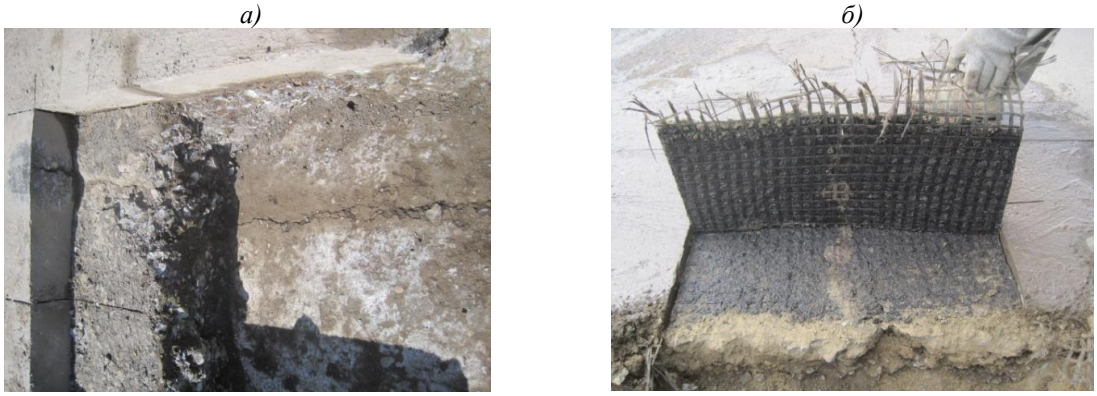
Выбоины – разрушения дорожных покрытий в виде углублений со сравнительно крутыми краями, образующихся в покрытиях вследствии местного разрушения материала покрытия (рисунок 3, б).

а) *б)*

Рис. 3. Колейность (а) и выбоины (б)

Повышение модуля упругости нижних слоев дорожной одежды приводит к образованию отраженных трещин (рисунок 4, а). Такой процесс наблюдался на участке автомобильной дороги «Омск–Майкапчагай», который проходит через объезд пос. Теренколь. Верхний слой основания состоял из отфрезерованного старого асфальтобетона с добавлением фракцированного щебня размером 20-40 мм, алюминиевого шлама и 5 %-го цемента, а нижний – из ГПС с добавлением алюминиевого шлама и 5 %-го цемента. Кроме того, между слоями покрытий были использованы геосетки (рисунок 4. б).

а) *б)*



а – по слоям; б – трещины, возникшие на покрытиях, укрепленные геосеткой

Рис. 4. Отраженная трещина в слоях дорожной одежды

При неустойчивости температуры воздуха, т.е. при ее большом суточном перепаде, и влажности грунта в теле земляного полотна теплообменный процесс проходит неустойчиво. Такие явления существенно способствуют образованию на поверхности асфальтобетонных покрытий микронеровностей, а при слабых основаниях – колейности. Эти явления особенно характерны для климатических зон с резкоконтинентальным климатом. Чтобы стабилизировать такие теплообменные процессы в слоях дорожной одежды необходимо снизить теплопроводность нижних слоев основания с применением низкотеплопроводных материалов. В связи с этим в разделе диссертации разработан алгоритм расчета по определению глубины промерзания грунта земляного полотна с учетом теплофизических характеристик материалов дорожной конструкции и коэффициентов уплотнения их слоев.

Методика оценки прочности слоев дорожных одежд с использованием пресс-штампа. Выбор места проведения испытаний осуществляется по указанию Заказчика. Перед испытанием определялась влажность грунта земляного полотна весовым методом, затем на назначенные места устанавливался пресс-штамп (рисунок 5) и измерялись показания упругого прогиба. Результаты измерений заполнялись в форму [4], затем послойно рассчитывались значения модуля упругости нижних слоев основания дорожной одежды.

После снятия показаний упругих прогибов, расчетным путем определяется величина фактического модуля упругости слоев дорожной одежды [2,4]:

$$E_i = 0{,}25 \cdot 3{,}14 \cdot p \cdot D \cdot (1 - \mu^2)/\ell, \qquad (2)$$

где p – нагрузка, подаваемая на пресс-штамп, МПа; D – диаметр штампа, мм; μ – коэффициент Пуассона, $\mu=0{,}32$; ℓ – величина упругого прогиба, мм.

а) *б)*

а – пресс; б – штамп

Рис. 5. Испытание слоев основания дорожной одежды прибором пресс-штамп

Ниже, в таблице 1 приведены результаты полевых замеров и расчетов, проведенных магистрантами КазАДИ [3].

Таблица 1

Результаты расчета модуля упругости слоев основания дорожной одежды

Нагрузка, МПа	Слой основания из материалов от разборки старой дорожной одежды с добавлением щебня фр. 20-40 мм, h=30 см						Слой основания из фракцированного щебня, h=20 см					
	Упругий прогиб, по показанию индикаторов			E_i, МПа	E_i с учетом темп. возд., МПа	$E_{ср}$, МПа	Упругий прогиб, по показанию индикаторов			$E_{ср}$, МПа	E_i с учетом темп. возд., МПа	$E_{ср}$, МПа
	правый	левый	средний				правый	левый	средний			
1	2	3	4	5	6	7	8	9	10	11	12	13
ПК 78+40												
45	65	77	71	134,0	120,6	121,2	31	20	25,5	373,0	335,7	349,8
90	137	151	144	132,1	118,9		51	45	48	396,3	356,7	
135	201	222	211,5	134,9	121,4		68	75	71,5	399,1	359,2	
180	268	281	274,5	138,6	124,8		101	91	96	396,3	356,7	
225	351	378	364,5	130,5	117,4		129	121	125	380,5	342,4	
270	422	405	413,5	138,0	124,2		154	141	147,5	386,9	348,2	
ПК 80+50												
45	80	71	75,5	126,0	113,4	118,8	23	27	25	380,5	342,4	350,1
90	136	148	142	134,0	120,6		51	46	48,5	392,3	353,0	
135	216	210	213	134,0	120,6		68	80	74	385,6	347,1	
180	280	274	277	137,4	123,6		98	93	95,5	398,4	358,6	
225	354	361	357,5	133,0	119,7		119	124	121,5	391,5	352,3	
270	434	461	447,5	127,5	151,0		151	145	148	385,6	347,1	
ПК 86+40												
1	2	3	4	5	6	7	8	9	10	11	12	13
45	68	73	70,5	134,9	121,4	120,2	28	22	25	380,5	342,4	351,0
90	139	144	141,5	134,4	121,0		51	45	48	396,3	356,7	
135	209	221	215	132,7	119,5		79	68	73,5	388,3	349,4	
180	291	272	281,5	135,2	121,6		99	94	96,5	394,3	354,9	
225	360	356	358	132,9	119,6		125	116	120,5	394,7	355,2	
270	441	427	434	131,5	118,4		144	152	148	385,6	347,1	

Появление различных видов деформаций и разрушений на поверхности дорожного покрытия в определенной степени зависит от погодных условий (температура и влажность), а также при несоответствии прочностных характеристик данной категории дороги фактическим условиям транспортного движения. Это особенно воздействует на разрушение дорожных покрытий в зонах с резкоконтинентальным климатом, где суточный перепад температуры достигает 30 ºС и выше.

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ON THE STRENGTH PROPERTIES OF ROAD CLOTHES ON THE HIGHWAYS OF KAZAKHSTAN OF LOCAL IMPORTANCE

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О ПРОЧНОСТНЫХ СВОЙСТВАХ ДОРОЖНЫХ ОДЕЖД НА АВТОМОБИЛЬНЫХ ДОРОГАХ КАЗАХСТАНА МЕСТНОГО ЗНАЧЕНИЯ

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Abstract

Currently, work is underway on the highways of Kazakhstan related to diagnostics, technical accounting and certification. The article presents some of the results of this work carried out on the roads of the Zhambyl region. The structural layers of road clothes are analyzed and their strength properties are evaluated. To compare the strength indicators of road clothing, the article also provides the construction of road clothing for roads of national significance.

Аннотация

В настоящее время на автомобильных дорогах Казахстана ведутся работы, связанные с диагностикой, техническим учетом и паспортизацией. В статье приведены некоторые результаты данной работы, проведенные на дорогах Жамбылской области. Проанализированы конструктивные слои дорожных одежд и дана оценка на их прочностные свойства. Для сравнения показателей прочности дорожных одежд в статье также приведена конструкция дорожных одежд дорог республиканского значения.

Keywords: highways, road clothing, structural layers, strength properties, coefficient of strength, modulus of elasticity

Ключевые слова: автомобильные дороги, дорожная одежда, конструктивные слои, прочностные свойства, коэффициент прочности, модуль упругости.

В последнее десятилетие в Казахстане существенно растут темпы дорожного строительства. Этот рост одинаково ощущается как на республиканских, так и на местной сети автомобильных дорог. Изменились требования к осевым нагрузкам с учетом интенсивности и состава транспортного потока. Отсюда в дорожном хозяйстве страны появляется новая проблема, связанная с повышением прочности дорожных конструкции и износостойкости покрытия. На республиканских дорогах, особенно на международных транспортных коридорах, эта проблема нашла свои конкретные решения, т.е. она входит в рамки стратегического развития автомобильных дорог Казахстана до 2015 г.

В настоящее время бурно продолжаются работы, связанные с реабилитацией международных транспортных коридоров, внедряются новые материалы и технологии передовых зарубежных стран. Кроме того, в рамках «дорожной карты» на местных дорогах Казахстана также ведутся работы, связанные с повышением транспортно-эксплуатационного качества дорожных покрытий и восстановлением искусственных сооружений. Таким образом, почти на всех дорогах Казахстана общего пользования, мостовых и инженерных сооружениях существенно усиливаются требования к их прочности. Несмотря на такие усилия, все же на дорогах местной сети планированные работы развернулись в основном в рамках среднего ремонта. На многих участках местных дорог значение интенсивности движения и состава транспортного потока значительно превышают нормативные значения соответствующих категории данных дорог. В связи с этим основной целью на местной сети все же остается повышение транспортно-эксплуатационных показателей дорог и уточняются объемы ремонтных работ. На этих дорогах несоответствие геометрических параметров земляного полотна и низкая прочность дорожных конструкции пока остаются за рамками восстановительных работ, планируемых по программе «Дорожная карта».

При учете и определении состава транспортного потока на дорогах Жамбылской области при

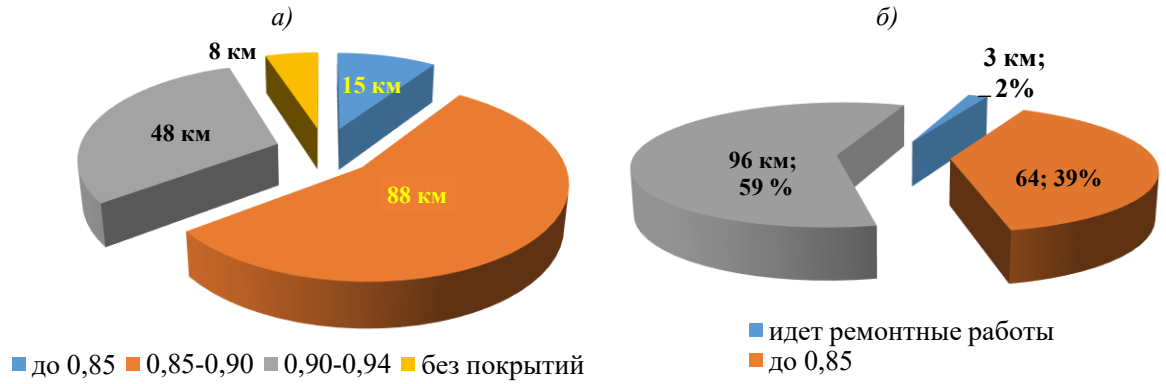
согласовании с Управлением строительства, пассажирского транспорта и автомобильных дорог акимата Жамбылской области были приняты учетные пункты. На каждом опорном пункте подсчет интенсивности движения проводился в течение 24-х часов. Для сравнения приводим некоторые результаты обследования, проведенные исследователями АО «КаздорНИИ» на дорогах республиканского значения (таблица 1).

По результатам подсчета интенсивности было определено, что максимальный поток движения, в основном, приходится на период с 7 до 9 и с 17 до 20 часов. Состав транспортного потока на различных дорогах носит разнообразный характер. Например, на дороге «Омск-Майкапшагай» (км 309) доля легковых автомобилей в потоке составляет 80,4 % доля автобусов – 0,9 %, 2-х осных одиночных грузовых автомобилей – 9,7 %, 3-х и 4-х осных одиночных грузовых автомобилей – 1,7 %, автопоездов – 2,6 %, седельных тягачей – 4,0 % и т.п. Из результатов подсчета интенсивности движения видно, что на автомобильных дорогах республиканского значения доля особо тяжелых автомобилей составляет 20-34 %, легковых – 65-80 %, а на местных дорогах – 3-6 % и 91-97 % соответственно.

Существующие дорожные одежды на местных дорогах, в основном, рассчитаны на транспортные средства, осевые нагрузки которых не превышают 6 т. Поэтому, их срок службы после среднего ремонта (капитальные ремонты практически отсутствуют) не превышает 3 года. Через 2-3 года (местами уже через год) на поверхности вновь уложенного слоя асфальтобетона повторяются те же дефекты, которые существовали на ранее уложенных покрытиях. Основание дорожной одежды практически не выдерживает тяжеловесной нагрузки (10-13 тонн), гораздо превышающей расчетную (6 тонн) [1,2].

Конструктивные слои дорожной одежды, представленные в таблице 2, никак не удовлетворяют современной осевой нагрузке [2]. Результаты вскрытия показали, что в основаниях дорожной одежды на большинстве местных дорог Жамбылской области используется природный гравий, в составе которого практически отсутствуют скелетообразующие (крупные) фракции, поэтому они не выдерживают высокие нагрузки. Для сравнения, в таблице также представлены конструкции дорожной одежды автомобильной дороги «Доссор-Кульсары-Бейнеу» и объездной автодороги г. Астаны. На первой, в основаниях дорожной одежды также используется природный гравий, в составе которого отсутствует скелетообразующая фракция, но здесь, во первых, ее общая толщина составляет 24,5 см (на 8,5 см больше) и, во-вторых, в составе основания также используется черный гравий, который выполняет функцию скелетообразования, не дающий возможность внутреннего сдвига материала основания.

Фактические значения модуля упругости на большинстве дорог Жамбылской области ниже требуемого значения. Это, в свою очередь, прямопропорционально связано со снижением коэффициента прочности дорожной одежды. Например, по данным КазАДИ им. Л.Б. Гончарова (2011-2012 гг.), проведенные на местной сети Жамбылской области, на участках автомобильной дороги «Саудакент-Жанатас-Каратау» значение коэффициента прочности колеблется в пределах $К_{пр}$=0,85-0,94, а на автомобильных дорогах «Саудакент-Жанатас-Каратау» до пос. Аса и «Тараз-Аса-Аккуль-Саудакент» (рис. 1, а,б) коэффициент прочности не превышает $К_{пр}$=0,85-0,94 и $К_{пр}$=0,92-0,93, соответственно. По данным АО «КаздорНИИ» (2009-2011 гг.) на республиканских дорогах значения коэффициентов прочности дорожных одежд не ниже $К_{пр}$=0,96 (см. таблицу 2).



б – «Саудакент-Жанатас-Каратау» (км 0-159);
б – «Тараз-Аса-Аккуль-Саудакент» (км 7-164)
*Рис. 1. Показатели прочности дорожных покрытий на участка**х а/д***

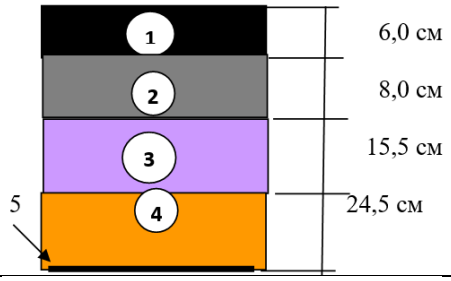
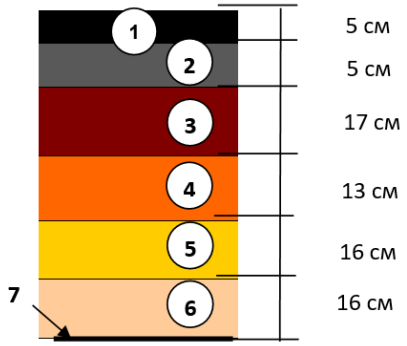
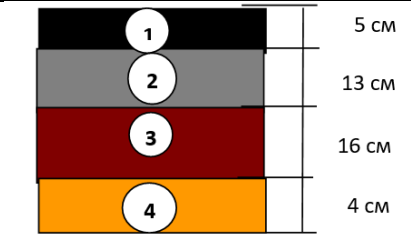
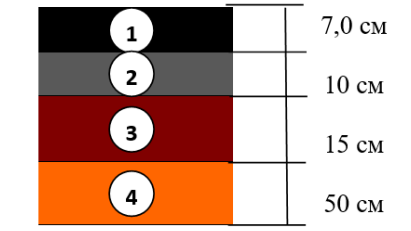
Таблица 1

Сравнительные результаты подсчета интенсивности движения на дорогах Казахстана

Автомобильная дорога	Легков. авт.	Автобусы	2-х осн. гр. авт.	3-4 осн. гр. авт.	Автопоезда	Седельн. тягачи	Др. виды трансп	Всего	Расчетная инть, ед/сут	Категория дороги		
										существующая	по СНиП РК	рекомендуемая
Республиканские дороги (участки дорог международного транспортного коридора) Республики Казахстан												
а/д «Омск-Майкапшагай», км 309, май 2011 г.	1481	17	179	31	47	79	13	1847	2735	III	III	II
	80,4	0,9	9,7	1,7	2,6	4,0	0,7	100				
а/д «Актюбинск-Уральск», км 248, июль 2011 г.	1758	55	170	230	153	147	4	2517	4815	III	II	II
	69,8	2,2	6,8	9,1	6,1	5,9	0,1	100				
а/д «Доссор –Бейнеу», км 2, июнь 2011 г.	1175	25	201	143	81	200	1	1826	3700	III	II	II
	64,3	1,4	11,0	7,8	4,4	11,0	0,1	100				
Местные дороги Жамбылской области												
Тараз-Аса-Аккуль-Саудакент, км 17, июнь 2011 г.	1107	24	31	21	12	12	10	1217	1457	IV	III	-
	90,9	2	2,51	1,82	0,99	1	0,78	100				
Тараз-Сарыкемер-Туймекент-Акшолак, км 5, июнь 2011 г.	7678	289	193	153	19	17	18	8357	9621	II	I	-
	91,88	3,46	2,31	1,83	0,23	0,20	0,22	100				
Берлик-Мойынкум-Уланбел-Шыганак. км 24, июнь 2011 г.	911	-	-	-	26	-	-	937	1067	IV	III	-
	97,23	-	-	-	2,77	-	-	100				

Таблица 2

Конструкция дорожных одежд на дорогах Казахстана

Автомобильная дорога	Конструкция дорожной одежды	Конструктивные слои
Дороги на международных транспортных коридорах		
«Доссор-Кульсары-Бейнеу» км 225+000 $N_ф$=5200 авт./с, $N_р$=9720 авт./с.		1 – мелкозернистый асфальтобетон; 2 – крупнозернистый асфальтобетон; 3 – черный гравий; 4 – природная ПГС; 5 – геотекстиль. Толщина д.о. – 54 см $К_п$=0,96, $Е_{тр}$=220 МПа
Объездная автомобильная дорога г. Астаны км 5+500		1 – м/з асфальтобетон; 2 – к/з асфальтобетон; 3 – черный щебень; 4 – балласт, фр.30-70 мм; 5 – Природный гравий; 6 – ПГС; 7 – геотекстиль Толщина д.о. – 72 см $К_п$=1,04, $Е_{тр}$=220 МПа
Дороги на местной сети автомобильных дорог Казахстана (по Жамбылской области)		
Тараз-Аса-Аккуль-Саудакент км 8+500		1 – холодный а/б; 2 – черный гравий; 3 – гравийно-песчаная смесь, фр. 0-30 мм; 4 – мелкий гравий. Толщина д.о. – 38 см $К_п$=0,86, $Е_{тр}$=180 МПа
Тараз-Сарыкемер-Туймекент-Акшолак км 14+000		1- холодный а/б; 2- старый а/б 3- гравийно-песчаная смесь 0-70 мм 4-природный гравий Толщина д.о. – 38 см $К_п$=0,92, $Е_{тр}$=180 МПа

Инструментальная оценка ровности дорожных покрытий осуществлялись методическими требованиями [3] (Казахстан) и был использованы толчкомеры ТЭД-2М и ИР-2 с программной обеспеченностью. Первый прибор был применен на участках а/д «Тараз-Аса-Аккуль-Саудакент», а второй – на а/д «Саудакент-Жанатас-Каратау-Респ. дорога», от трассы «Саудакент-Жанатас-Каратау-Респ. дорога» до с. Аса и др. Для сравнения были приведены результаты обследования АО «КаздорНИИ» на а/д «Актобе-Уральск-гр. РФ», «Омск-Майкапшагай» и «Костанай-Сурган».

Результаты показывают, что на поверхности покрытия на дорогах Жамбылской области практически ровность отсутствует, т.к. при этом доля участков с неудовлетворительной ровностью составляет 52-56 % (до 12 % на республиканских дорогах), удовлетворительной – 14-26 % (35-62 %), хорошей – 7-19 % (20-52 %), отличной – 5-9 % (13-21 %) и дороги без покрытий или дороги с разрушенными покрытиями – 0-10 % (отсутствуют). Неудовлетворительная ровность покрытия на дорогах республиканского значения в основном связана с некачественной заделкой трещин или другими видами дефектов.

Вышепредставленная информация дает возможность правильно выбрать вид ремонтных работ по участкам дорог и их состав. На примере Жамбылской области выяснилось, что на местной сети категория дорог, особенно на пригородных участках, значительно снижена и конструкции дорожных одежд не удовлетворяют фактической нагрузке, в результате которых межремонтные сроки не выдерживаются. Экономия денежных средств на ремонтные работы методом замены вида ремонтных работ на ступень ниже существенно сокращает их сроки

службы и тем самым влияет на качество содержания дорог не только местного значения, но и на УДС городов и крупных населенных пунктов.

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